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The Metallurgy of Titanium.

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We cannot expect, within the limits of this paper, to treat this subject exhaustively, but will endeavor, in the following, to present it in as concise a manner as is consistent with a clear exposition of its importance.

Ores of titanium, titaniferous iron ores [that is, iron ores containing a notable amount of titanic oxide (TiO_2)], say not less than 5 per cent., generally 10 to 20 per cent. and frequently more, up to 40 per cent. or thereabout, occur all over the world in immense quantity, "in mountain masses," constituting in some localities, as in Sweden, Norway, Canada, the Adirondacks (N. Y.), in North Carolina and other States of the Union, the geological formation itself, the igneous rocks having, in many places, been so permeated with the metallic oxides as to justify their being called iron ores.

As a rule they are Bessemer ores, quite free from phosphorus and sulphur, though not invariably so. When the percentage of titanic oxide is very high, that of the iron is low, but the proportions do not necessarily vary in the same ratio; that is, a rich ore may contain more titanic acid than one lower in iron. The percentage of iron varies, being as low as 35 to 36 per cent. in real ilmenite. It is more generally not less than 50 to 55 per cent., reaching often an average of 58 to 60 per cent. and as high as 63 to 65 per cent.

It is obvious that if these ores were to be considered in the same light as other iron ores, equally rich in iron, they would form an excellent stock for blast-furnaces for years to come, as their supply might be called inexhaustible, and they could take the place, in part or wholly, of other iron ores free from titanium, of which the exhaustion, in a comparatively short time, in certain districts can be foreseen, owing to the tremendous demands made on them by our modern monster blast-furnaces. In this sense we are justified in saying that the metallurgy of titanium is one of preeminent importance, as it implies the use of these ores, which may justly be called the resources and reserves of the future, when they will be appreciated at their full value, and the prejudices against them will be removed, as gradually they are getting to be. "The verdict against them" as it has been said by others than ourselves in the discussion of some of our papers on the subject, read before the American Institute of Mining Engineers, "is unjust, based on entirely insufficient grounds and far from creditable to the progressive spirit of American metallurgy."

Generally low in silica, free from impurities, such as phosphorus and sulphur, they are particularly well adapted in the blast-furnace for the production of a stock well suited for the open-hearth process (either acid or basic), which is gradually supplanting, at least competing more seriously with, its rival, "the pneumatic or converter process."

Some of the objections raised against the use of these ores in the blast-furnace are so unreliable, so contradictory, so much in opposition to actual facts, that it is really

puzzling to find out on what ground they were originally founded.

Opinions in this respect seem to have been taken already made, without any personal control or even desire to ascertain the authenticity, reality or importance of certain statements, and handed down from one to another.

We have not been able to find one metallurgist who could tell us he had used these ores or that, using them, he had experienced any trouble thereby. They have brought forward the stereotyped objections and rested there: "*Sit pro ratione voluntas!*"

These objections have appeared in many scientific publications (easily quoted), and often simultaneously with their refutation by actual experiments on the subject. For instance, to mention one of them, it has been stated that the presence, in a blast-furnace slag, of 1 per cent. of titanic acid, or thereabout, was sufficient to render it so infusible as to transcend the heat capacity of the blast-furnace, the slag being so pasty as to render its tapping impossible or practically so; and still, slags, containing 25 to 35 per cent. of titanic acid have been run for over twenty years from blast-furnaces put up in the Adirondack wilderness some fifty years ago, and thousands of tons of such slags which we have seen and analyzed, form, at the present day, an embankment around the cast-house of the old furnace, of 15 tons daily capacity, still standing as a testimony that this statement as to infusibility of titanic slags cannot in any manner be sustained.

For seven years blast-furnaces have been run in England, at Norton-on-Tyne, with ores containing 40 per cent. of titanic acid and 35 to 36 per cent. of iron, making 200 tons of pig-iron per week. Analyses of the slags have been published by the chemist in charge, as well as all the data as to composition of ores, charges in coke, ore and fluxes. The slag contained, on an average, 36 per cent. of titanic acid.

We ourselves have run for several months a small blast-furnace of 3 to 4 tons capacity, put up at Buffalo, to demonstrate the economy of the smelting of this class of

ores, when properly dealt with. We have tapped hundreds of tons of slags containing 32 per cent. titanic acid, which ran 50 feet from the furnace perfectly liquid. In crucible tests we have made in a furnace with "natural draft," compounds containing 63 to 64 per cent. of titanic acid were obtained, which we have been able to cast in molds.

We give below an analysis of the slags mentioned above as an illustration:

	I.	II.	III.	IV.
Silica	27·83	26·72	15·90 to 17·50	0·67
Titanic acid	36·18	25·11	34.38	64·80
Lime	24·36	25·81	22·10	14·30
Alumina	9·18	11·86	11·23	10·50
Magnesia	0·60	5·99	9·70	8.30
Oxide of iron	1·86	3·46	4·30	0·90

I. Slag run at Norton-on-Tyne from Norwegian ilmenite containing 40 per cent. titanic acid, 35 to 36 per cent. iron. Analysis by chemist in charge. Wm. M. Bowron, *Trans. A. I. M. Eng.*, Vol. XI, p. 159.

II. Slag run in Adirondacks in 1856. Average specimen from several hundred pounds of slags picked up from the cinder bank in 1893 by A. J. Rossi. Analysis by Ledoux & Co.

III. Slag run in the small Buffalo furnace, put up in 1896, at the New York Car-Wheel Works by A. J. Rossi. Analysis by the chemist of the works.

IV. Compound made in crucible in a furnace with natural draft and poured out in molds. The ores used contained 15 per cent. TiO_2, and on an average 58 per cent. iron.

Other objections, such as "titanium deposits," in the boshes, according to some; in the hearth, according to others, have been advanced against the use of these ores, and, to accept the "sworn testimony" of some blast-furnace managers in a suit in which we were called as expert, "$\frac{3}{4}$ of 1 per cent.," "$\frac{1}{4}$ of 1 per cent.," mere "traces" of titanic acid in an iron ore, are as sure to produce these deposits as larger percentages. We have been for twelve years technically in charge of the blast-furnaces of the Boonton Iron Works (Fuller, Lord & Co.), in 1876. Our ores contained normally from $\frac{3}{4}$ of 1 per cent. to 1·25 per cent. titanic acid, and never did we observe such deposits in our two furnaces. We did not even at that time attach importance enough to the presence of titanic acid cinder ores to determine it in our analyses otherwise than as a curiosity.

As regards larger percentages of titanic acid the suc-

cessful and continuous running of the Adirondack furnaces for twenty years, that of the English furnace at Norton-on-Tyne for seven years (as attested by a mention of this furnace in a paper read before the British Iron and Steel Institute at their annual meeting in 1894), that of our own small blast-furnace at Buffalo for some months, ought to dispose of these objections, or at least limit them to special cases, as when, by accident, the objectionable phenomena might have been observed in an abnormal and deranged working of a furnace; smelting, possibly unknowingly, a mixture of ores in which titanic acid was present; and it might well be asked whether such derangement was not *post hoc* rather than *propter hoc*.

It is well known that obstructions of a similar character and composed almost entirely of lime have been observed in the smelting of ores free from titanium. One of these infusible blocks in a blast-furnace was stated to weigh 30 tons. The cause of their formation has been attributed to the excess of limestone charged as flux and of lime in the cinder; very basic silicate of lime being quite infusible *per se*. In such conditions titanium deposits may have contributed to the obstruction without being the cause of it.

Some twenty-five or thirty years ago the chemist was a luxury in a blast-furnace plant. A good practical rule of thumb was followed with sufficiently constant success with ores varying but little year after year; but when the demands of industry justified an increase in the number and size of furnaces and consequently necessitated a more abundant supply of ores, new ores had to be mixed with those generally used, and the presence of titanic acid being likely ignored, as well as the manner of dealing with it properly, fluxes may have been indiscriminately added, causing trouble, and the titanic acid was conveniently made the scapegoat. When we say fluxes, we mean calcite, as, for many years, limestone (calcite) was considered the only admissible or safe flux in a blast-furnace. Indeed, Percy himself, in his admirable and classic book on metallurgy, states that, "as magnesia increases the infusibility of a slag, dolomite as a flux, instead of limestone, should obviously be avoided."

This is another prejudice which has lasted for years and has been exploded only within the last twenty years or thereabout. As every metallurgist knows now, dolomite is preferable to calcite as a flux, as it increases the fluidity and fusibility of the slag, at the same time removing sulphur fully as efficaciously if not actually better than lime.

Titanate of lime is more infusible still than silicate of lime, and the addition of lime in excess, on general principles, may possibly, with ores very low in silica and containing a large amount of titanic acid in the mixture, have caused the slag to prove less fusible; but we should not forget, however, that a silico-titanate of lime, containing about equal percentages of silica, titanic acid and lime—"sphene," as it is called—is as fusible in a blast-furnace as any good foundry-iron slag and considerably more fusible than silicate of lime; so that the presence of titanic acid should have increased the fusibility, if a sufficient amount of silica was present, instead of diminishing it. We may refer to Analysis No. I of the slags run at Norton-on-Tyne as an example.

As to "titanium deposits," to be called strictly so, that is, formations of nitrides and cyano-nitrides of titanium, of a copper-red color, or of a metallic titanium, as it was claimed by some, they may have been possible in a serious derangement of the working of a blast-furnace occurring under circumstances independent of its presence and due to causes entirely foreign to it; the titanic acid being then an "accessory after the deed," and conveniently assumed to be the principal cause of the mischief.

We have seen in Pittsburg a very fine large specimen of such titanium deposit; it was copper-red and kept religiously under a glass case. But the well-known metallurgist who had it was conscience-stricken and owned frankly to us that he had had the curiosity to have it analyzed, and that it was found to contain 98½ per cent. of copper. As is well known, for many years, and until the researches of Wöhler, it was believed that titanium was a red metal, like copper.

In short, titanic acid, properly dealt with in the blast furnace, will not necessarily prove the cause of trouble-

Slags containing some 35 per cent. of titanic acid will run as fluid as silica slags, and if in an iron ore the titanic acid or oxide (TiO_2) be treated as so much silica, and be depended upon and calculated to form one of the principal elements of the slag, with such amount of silica as will be necessarily and unavoidably contributed to the slag by the limestone (as the ores and the ashes of the fuel), and if a dolometic stone be used as flux instead of a calcite, titano-silicates of lime, alumina and magnesia will be found to form a very fluid fusible and good slag, and no titanium will remain in the furnace to cause any trouble in a normal or ordinary running.

It is this addition of dolomite as a flux, instead of calcite, with which we have experimented with success in our small furnace at Buffalo. (See analysis of slag III). Both in the Adirondacks (analysis II), and in England (analysis I), at Norton-on-Tyne, the composition of the slag was different, in this sense, that the silica was present to nearly an equal percentage with lime and silica, reproducing practically the composition of the mineral sphene perfectly fusible in the blast-furnace—*a silico-titanate of lime.* In England it was obtained by the addition to the ore, of which the composition is given below, of siliceous flux, in the shape of old bricks, besides the calcite addition, considered indispensable at the time.

REUSED AT NORTON-ON-TYNE—NORWAY ILMENITE.*

Titanic acid	(average of cargo)	39·20
Silica		5·70
Ferric oxide		18·59
Ferrous oxide		30·00
Manganese oxide		0·60
Alumina		2·89
Magnesia		2·80
		99·78
Iron		36·34 per cent.

In the Adirondacks, siliceous fluxes were also added, but they were furnished by the Labrador feldspar, costing

* Analysis by Wm. M. Bowron, chemist in charge. See Bowron paper quoted above.

nothing and saving that much limestone. The ore on an average contained:

Silica	2·50
Titanic acid	13·50
Alumina	1·50
Magnesia	0.90
Oxide of manganese	0·13
Phosphorus	0·020
Sulphur	1·052
Oxide of iron	81·90
Metallic iron	58·43 per cent.

We have published on these questions several papers*, to which we refer the reader for more complete information. In one of them will be found all the data of the run of the small experimental furnace erected at Buffalo.

We should remark here that all that we have said above applies to ores really titaniferous; containing, say, not less than 5 per cent. titanic acid, smelted alone. As to ores containing 1 per cent. of titanic acid or thereabout, our practice of twelve years in Boonton, N. J., and that of other furnaces who bought from us the same ores that we have used (or similar ones of Morris County, in which the average of titanic acid is from 0·55 to 1 per cent., such as those of the Hibernia Mine, Mount Pleasant), and are using yet, cannot leave any doubt that ¾ per cent. to 1 per cent. titanic acid in the ore mixture can be completely ignored so far as affecting in any manner the run of the furnaces or the charges.

But, even assuming an inferior limit of 0·50 titanic acid admissible in a mixture, it is difficult to conceive why ores from North Carolina and elsewhere, containing 64 per cent. of iron and 5 per cent of titanic acid, cannot be used in mixture with ores free from titanic acid to the extent of 10 per cent., since by so doing the mixture would contain only 0·50 per cent. titanic acid, an amount present in the charges of a number of blast-furnaces we could quote, and immense

* Titaniferous Ores in the Blast-Furnace. *Transactions American Institute Mining Engineers*, vol. xxi, p. 832. Smelting of Titaniferous Ores. *Iron Age*, Feb. 6th and 20th, 1896.

deposits of excellent ores would be made available as blast-furnace stock.

But prejudices are difficult to eradicate when they are deeply rooted, even if arithmetic is resorted to to demonstrate their fallacy.

There is another objection, more specious than real, which has been raised against the smelting of titaniferous iron ores, namely, that of the relative economy offered. There is no doubt that, with such ores as were used in England at Norton-on-Tyne, and which contained only 36 per cent. iron with 40 per cent. titanic acid and 10 per cent. of other gangue (in all, 50 per cent. of barren materials), the addition, as flux, of as much lime and as much silica as of titanic acid in the ores, there must have been something like 4½ tons of slag to melt per ton of iron smelted, and the process may not have proved economical as to fuel; but would it have been any more so with ores free from titanium but containing such an amount of gangue and 40 per cent. of silica? In the Adirondacks, the ores being much richer and containing so much less titanic acid (15 per cent. instead of 40 per cent.), the addition of rock as flux did not very materially affect the economy; but in our small furnace at Buffalo, as no other flux but dolomite was added (the titanic acid being treated as so much silica), the smelting proved as economical (as the record of the run showed) as that of any other ore free from titanium and containing the same amount of silica as the Adirondack ores contained of titanic acid.

But this question of economy of fuel, assuming even it were real when dealing with such ores as it would be contemplated to smelt without admixture, that is, rich ores containing moderate amount of titanic acid, is of but little importance if, as we will see presently, the properties of the pig metal yielded by this class of ores are such that it commands a much higher price on the market than an ordinary good foundry iron.

It is the concensus of opinion, admitted even by those most obstinate in their prejudices, that the pig-iron smelted from really titaniferous ores smelted alone, or in important

proportions with other ores, is "strong," "wonderfully good," "a splendid iron," "all that can be desired," for such are the expressions met with at every step when one is referred to the literature of the subject. The iron made at Norton-on-Tyne in 1869–1876, it is said in the *Journal* of the British Iron and Steel Institute, "went to Sheffield for armor plates on account of the toughness that this iron not only possesses but imparts to others in admixture."

It is essentially an open-hearth stock. Analyses of the pig-iron made by us at Buffalo and that of the Adirondacks (the same ores were used in both cases) showed phosphorus traces; silicon, 0·11 to 0·13; carbon, from 1·86 to 3·50 practically all combined; the fracture had very much the appearance of that of steel. It is eminently a chilling iron, well adapted for car-wheel mixtures. Introduced into such mixtures, not only does it increase the strength of the metal constituting the body of the wheel, but it gives at the tread a deep, strong and hard chill, resisting attrition and shocks remarkably well, as was attested by parties interested in this line of manufacture, and for whom and with whom we have made extensive tests with this special iron.

Briefly stated, the results were as follows: The addition of 5 per cent. of titaniferous pig to a normal mixture for wheels increased the chill on chill blocks from 1·062 inches to 1·375 inches, and the transverse strength from 3,250 pounds to 3,775 pounds per square inch. The addition of 10 per cent. titaniferous pig brought the chill to 1·562 inches, with a transverse strength of 3,600 pounds per square inch; and the addition of 25 per cent. of this titaniferous pig, white or mottled white as it was, without affecting the original strength, raised the depth of chill to 1·750 inches.

In another establishment the wheel mixture showed a tensile strength of 24,500 pounds, and a transverse strength of 2,500 pounds per square inch. The addition of 10 to 15 per cent. of titaniferous pig to a cheap grade of foundry pig, showing only 18,500 pounds tensile strength and 1,900 pounds transverse, raised the strength to 25,500 pounds and 2,730 pounds, respectively, per square inch, with a much

deeper chill than in the wheel mixture, and at a cost of several dollars less per ton.

Strange as it may appear at first, this titaniferous pig-iron does not contain titanium to any important extent. Rarely does it contain more than a few tenths of 1 per cent.; more generally only a few hundredths of 1 per cent. The influence of titanium in the smelting would seem thus to be one of purification, by eliminating obnoxious elements more than a direct one; but we will see later on that it is not necessarily always so. Titanic acid is not reduced by carbon at the temperature attained in a blast-furnace, contrary to what happens with silicon. It requires the high heat of the electric furnace to secure such a reduction. If titanium is found in the pig-iron, to some small extent it is due, according to certain special reactions, possibly to the presence of alkaline cyanides formed in the blast-furnace in the vicinity of the tuyeres, forming small quantities of cyano-nitride of titanium, which is carried out by the iron, coating it *superficially*, as it has been observed in some furnaces, and giving to the pig-metal a copper-colored hue. This may possibly explain why titanium is found in such small percentages and why it is not found in the free *metallic* state in the analysis, but as *carbide* and *cyano-nitride*, or both. That titanic oxide is not reduced directly by carbon in the blast-furnace and, if at all, but to a very small amount, seems to be proved by the fact that ores containing as much as 40 per cent. of titanic oxide yielded a pig-iron containing titanium 0·00 to 0·03 per cent. (analysis of pig-iron smelted from ilmenite, made at the School of Mines of Paris), while the pig-iron smelted from the Adirondack ores containing 13 to 15 per cent. titanic oxide (TiO_2) analyzed 0·07 to 0·12 per cent. titanium; the conditions of running of the furnace in both cases seem to have had more to do with the reduction, small as it was, than the percentage of titanium in the ores.

The question suggests itself: Since pig-iron smelted from titaniferous ores, though containing but very small amounts of titanium, and that not in the metallic state but as carbide or combined with nitrogen and carbon as cyano-nitride,

what would be the effect of the presence of titanium as metal, in such products as cast-iron or steel, in more important percentages?

We know that nickel added to steel, to the extent of 3 to 5 per cent., imparts to it valuable properties; that even added to cast-iron it increases the strength, though at a material increase of cost. We know also that chromium and molybdenum have special influences on the properties of steel. Could not titanium, as a metal, secure valuable though different or similar properties? But since pig-iron does not appear to contain any titanium to an available extent, and that amount not even as free metallic titanium, and that, whatever may be this quantity, it disappears in the process of refining pig-iron for making steel, the only way to secure the presence of titanium to any important extent in pig-iron or steel is to add it to the finished product in the state of alloy, as *ferro-titanium*, in the same manner as ferro-chrome or ferro-nickel or ferro-manganese is used to incorporate these metals in steel. Such alloys we have manufactured last year by the ton, and of this manufacture we will now briefly speak:

Professor Moissan, in his well-known experiments on the reduction of refractory metallic oxides, has been able to obtain small quantities of metallic titanium by the reduction of purified rutile (titanic acid, TiO_2) by carbon, in a lime or magnesia crucible, under the influence of the heat secured by a powerful electric current. Moissan's method of using a small furnace, with horizontal electrodes, between which the electric arc was started *above* the materials to be reduced, and not in contact with them, has become classical. But the product obtained contained carbon, and was indeed carbide of titanium for a great part, and had to be purified by repeated treatment with fresh quantities of titanic oxide. Such experiments, although of great interest in the laboratory, could not, of course, form the basis for the production of commercial titanium alloys, as the low price of a product is a *sine qua non* of its practical use. Furthermore, titanium carbide, as obtained by Moissan experimentally, on a small scale, and which can

be obtained on a larger scale much more easily than the metallic titanium, contains *titanium combined* with carbon in definite proportions. It has special properties, principally of hardness, which it may impart to mixtures; but whether valuable, as they may be, are quite different from such properties as could be expected from titanium introduced in a metal (such as cast-iron and steel) in the free metallic state, as is nickel, for instance.

By the method we have followed we have manufactured alloys of titanium and iron, containing from 10 per cent. to 75 per cent. of titanium, and either practically free from carbon or, if containing carbon, containing the latter in the *graphitic state* so that the titanium was present as *free metal* alloyed with iron and not in the state of carbide.

As the percentage of titanium in these alloys increases, their fusibility diminishes. Thus, 10 per cent. titanium alloys do not melt at the temperature of fusion of cast-iron and steel, and they are incorporated in the molten mass by a sort of dissolution just as platinum, infusible at the above-mentioned temperatures, "will fuse in contact with steel at a temperature at which even the steel itself, if not affected, alloying in all proportions with iron," as shown by the results obtained by Faraday and Stoddart. Ten per cent. titanium alloys containing carbon (graphitic) present the appearance of a No. 1 graphitic pig-iron, the particles of graphite shining brilliantly through the mass; they are soft under the hammer, forging and flattening though quite resisting. However, when once torn apart, so to speak, in small fragments, they flatten to such an extent as to admit of their being easily pulverized. The powder, sifted through an 80-mesh sieve, showed by analysis the same percentage of titanium as the solid piece itself, thus demonstrating a very even dissemination of the graphite through the mass. As the percentage of titanium increases, the grain of the fracture becomes closer, the other characteristics remaining the same.

The titanium alloys, free from carbon, are of a silver-white color, exhibiting a coarse crystalline structure, when the titanium is low (about 10 per cent.), the grain becoming

finer as the titanium percentage increases. With 35 per cent. titanium the fracture is that of a solid mass, showing no crystallization, at least to the naked eye. The color is of a dull silver-white when the alloy contains over 45 per cent. to 50 per cent. titanium.

All these alloys, the carbon alloys as well as the others, are much lighter than cast-iron, their specific gravities varying with the amount of titanium. We have found it to be 5·60 for a 25 to 30 per cent. alloy free from carbon, and about the same (5·74) for a 10 per cent. to 12 per cent. alloy with carbon; metallic titanium having a specific gravity of 4·87, cast-iron one of about 7·00 and wrought-iron one of 7·788.

It would carry us too far to describe in detail the manufacture of these alloys, and we refer the reader to the article on this subject which has appeared in Vol. IX *Mineral Industry*, 1901. We will briefly recapitulate its salient points:

The electric furnaces we used were of the well-known type of the Siemens furnace of 1879, modified, to some extent, for our purpose. It consisted essentially of a large block or parallelopiped, as of agglomerated graphite, properly insulated with refractory materials of bricks. A cavity in the block formed the crucible or hearth, and in this cavity, by means of a proper system of chains, pulleys, etc., the vertical carbon electrode or cathode, formed of one or several carbons bunched together, could be worked up and down. The graphite block was connected at its lower part with one of the terminals of the current and formed thus the anode, while the vertical carbon, by means of flexible cables, was connected with the other pole; the materials to be reduced being charged in the cavity of the furnace, and the vertical carbon lowered to almost a contact, the arc was started through the materials of the charges, and the reduction proceeded until completed. The product could be removed at the end of the operation, or the alloy (when liquid) tapped off.

According to size of cavity or crucible, intensity of current and percentage of titanium desired, we could make from

150 to 250 pounds of alloy in about two hours with about 200 horse-power. When making alloy containing carbon, the charges consisted of the titaniferous oxides mixed with the proper amount of carbon, the materials being used in powder and strongly compressed. Some of the ores used were the Adirondack ores mentioned above, which could yield readily an alloy containing from 12 to 13 per cent. titanium. By using Canadian ores containing 35 per cent. titanic acid and about 35 per cent. iron, we obtained alloys containing as much as 35 per cent. titanium. The use of rutile—natural titanic acid—nearly pure and containing some 90 to 95 per cent. of TiO_2 would of course have given us alloys as high in titanium as might have been desired, but, until the late discoveries of special, extensive and geologically interesting deposits of rutile in Virginia about one year ago, its cost, $250 to $350 a ton, excluded it, from the standpoint of economy. Even now, and though the price of rutile has fallen to fully half of what it was, this price is considerably higher than that of titaniferous ores—high in titanium (40 per cent. titanic acid), which can be had at the cost of ordinary iron ores.

We have obtained from the Adirondack ore containing 58 per cent. iron and 15 per cent. of titanic acid (TiO_2) or say 9 per cent. of titanium, alloys of 75 to 80 per cent titanium by the special method which we have followed, which is a sort of igneous concentration, as we have called it. It consisted in submitting at our furnaces a mixture of these Adirondack ores with a quantity of carbon sufficient to reduce the iron oxides it contained, but not the titanic oxides, to a heat but a little higher than that attainable in the blast-furnace, adding to the ore a small quantity of lime or good limestone so as to form practically, with the titanic acid of the ores, a titanate of lime, with such small amount of magnesia and alumina (or silica) the Adirondack ores could contribute to the slag. We thus obtained, as a by-product, a titaniferous pig-iron, containing now but a few hundredths of 1 per cent. (0.032 per cent.) of titanium possessing all the valuable properties of the metal smelted in the blast furnace from this class of ores and, at the same time, as slag, a con-

centrate of the titanic acid of the ore to the extent of 56 to 58 per cent. TiO_2, with no more iron in this slag than is ordinarily met in a blast-furnace cinder; that is, about 2 per cent. iron, 56 per cent. titanic acid, corresponding in round numbers to 31 per cent. titanium. Thus by treating 100 parts of this concentrate as we did the ore, we could theoretically obtain an alloy containing, say 31 per cent. titanium acid, 2 per cent. iron, or 94 per cent. titanium, or, by mixing it with proper quantities of iron ore, any percentage of titanium desired. But, as we will see, this concentrate proved of a particular value when making alloys free from carbon.

All the alloys made with carbon, as reducing agent, contained from 7·50 to 8·50 per cent. carbon and occasionally even 9 per cent., of which 0·10 per cent. or less was combined carbon, the remainder graphitic carbon. In order to obtain alloys free from carbon, or practically so, we used a method based on the well-known property of aluminum to reduce metallic oxides. This property has formed the subject of many experiments in the laboratory for over fifty years, but it has been considered necessary for success to use the aluminum as an impalpable powder and to mix it, in that state, with the powdered oxide to be reduced.

Of recent years Dr. Goldschmidt has succeeded in utilizing industrially to a certain extent the reducing power of aluminum in pulverulent form. This method consists, after having mixed intimately together the powdered aluminum and the powdered oxide, in placing in the mass a primer formed of powdered aluminum and an oxide capable of readily yielding a portion of its oxygen, such as sodium or barium peroxide, starting the primer itself by igniting an inserted ribbon of magnesium. The heat of formation of alumina (in the primer), the aluminum oxidizing at the expense of the oxygen of the oxides, is so intense that, by contiguity, it is imparted to the whole mass and the reduction proceeds instantaneously, so to speak, often tumultuously and dangerously so, without the intervention of any external heat. It is not for us to discuss the value of this process any further than to say that the rapidity of the reaction

itself creates in the metal or alloy obtained a certain uncontrolable amount of aluminum which cannot be removed without a remelting of the product, and that some of the materials of the vessel in which the operation is carried on passes also into the product—silica, if a clay vessel be used; carbon, if a graphite one be resorted to; so that it cannot be claimed to produce strictly pure alloys or metals. But the main drawback to its industrial use on a large scale, aside from the manipulations required, is the original cost of the aluminum in powder, which is several times that of aluminum in ingots or scrap.

We have found that it is not necessary to use the aluminum in powder to secure the reducing action, but that if a bath of aluminum be maintained at the proper temperature, in an electric furnace, for instance, like the one mentioned above, the metallic oxides (the titanic acid in the case and the iron oxides charged in this bath) will be reduced, the temperature rising from the heat of formation of alumina to such an extent as to allow the moderation of the external source of heat first applied until the reduction is complete or nearly so. The metal or alloy obtained can then be kept liquid by increasing the intensity of the current before being tapped, and easily deprived, by a fresh addition of oxide of iron, of the aluminum it may contain, or, by proper additions, of any other impurities it may be considered desirable to remove.

Furthermore, in the Goldschmidt process, if titaniferous iron ores are used as raw materials, the amount of powdered aluminum to be added must be such as to reduce also the oxides of iron, which is paying rather dear per pound of iron reduced (as it requires nearly one-half pound of aluminum per pound of iron), unless rutile be used, and then its price comes as a very important factor.

By using, in starting, the titanic concentrate mentioned above as containing some 30 per cent. titanium and 2 or 3 per cent. of iron only, we have only to add aluminum to reduce the titanic acid, and if lower alloys are wanted, dilute, so to speak, the high alloy obtained, in a bath of iron. We have thus manufactured alloys of titanium containing from

10 to 75 per cent. titanium and from 0·10 per cent. to 0·60 carbon or thereabout at a cost not materially higher than the carbon alloys.

In the tests we have made of the titanium alloys for seasoning cast-iron, we have invariably used the carbon alloys and, by preference, alloys containing 10 to 13 per cent. titanium. In an experiment with steel we have used the alloys reduced with aluminum and practically free from carbon.

We have added the carbon alloy to cast-iron in crucible in lumps; in the ladle in small pieces or in powder; in the cupola in large lumps and also in powder, and the results have been practically the same. An addition of 3 per cent. or thereabout of a 10 per cent. titanium alloy appears to be amply sufficient to secure such results as an increase of 20 to 30 per cent. in the tensile strength of cast-iron, and proportionately as much in transverse strength. Results of such tests have appeared in papers read by us before the American Society of Mechanical Engineers (Milwaukee Meeting, May, 1901, Vol. XXII, of *Transactions*) and at the Annual Meeting of the American Foundrymen's Association, June, 1901, Buffalo, Vol. X, *Transactions*, Part I, to which papers we refer the reader.

Since then we have made other equally successful tests in different establishments, car-wheel works and others. We will briefly recapitulate them:

In general, the results of tests of 100 bars square 1 x 1 x 12 inches between bearings, and round 1⅛ inches diameter by 18 inches long, or thereabout, showed that by adding in the cupola, in good-sized lumps, 3 per cent. of a 10 per cent. alloy, or the same amount in powder in the ladle, we could bring the original strength of a good No. 2 coke-iron, showing 24,500 pounds tensile and 2,450 pounds transverse strength per square inch up to that of an excellent Scotch charcoal pig-iron or higher (in fact, 28,800 pounds tensile and 2,900 pounds transverse); and that by a similar addition of alloy to this Scotch charcoal pig we could bring the strength to some 32,500 pounds tensile and nearly 3,300 pounds transverse strength. As the price of this charcoal

pig-iron was $29 while that of the coke-iron was $15 at the time, and as they were used in mixture for special foundry purposes, it is clear that a mixture of the coke-iron treated with the alloy and of the coke-iron itself not treated, could be used with great advantage as to cost of mixture for the same strength secured; the addition of the the alloy to the extent mentioned to the coke-iron increasing the cost of the latter but a fraction of the difference of prices ($15 and $29) between the two original pig-irons.

Our tests with steel have so far been limited to crucible steels, and enough has been observed to show that the influence of titanium, introduced in steel in the metallic state, has been to increase considerably the ductility, as proved by the remarkable elongation, contraction of area and limit of elasticity observed in high carbon steels containing 1·25 per cent. and even 2 per cent. carbon. The quantity of titanium found in the steel by analysis varied from 0·89 per cent. and 10·1 per cent. to 0·10 per cent. As the effect of even such small quantities as the latter one (0·10 per cent.) was very marked, and as, in these cases, 0·10 per cent. did not represent what could have been expected from the addition of the alloy, the question arises: Has not titanium an indirect action, when thus added to steel, besides a specific one?

It has been suggested that in the same manner as manganese removes oxygen from steel in the Bessemer process, as also in the open-hearth and even in crucible steel, titanium may not only act as a deoxidizing agent—much more powerful still than manganese—but also as removing from the steel the nitrogen it undoubtedly contains and which has an unfavorable influence on its strength. The odor of ammonia so noticeable in the open-hearth process proves the presence of nitrogen very decidedly. As is well known, titanium burns in nitrogen at 800° C. with incandescence, just as iron burns in oxygen. If so, the use of the alloy, even when containing carbon, would be well indicated in the open hearth as also in the converter, since it could be used as a recarburizer, on account of the high percentage of carbon it contains; as a deoxidizer (with or without ferro-

manganese); and as a denitrogenizer, so to speak; and, in the case of small converters for steel castings, the heat of formation of titanic acid, which is much higher than that of silica, would prove advantageous in raising the temperature of the bath even were but a small percentage of titanium to remain ultimately in the finished product. If by such use open-hearth and converter steel could be so improved as to compare better as to strength with crucible steels, and the latter be also improved to the extent it appears to have been in our first tests, there would be opened for these alloys a large field of usefulness, and for these titaniferous ores a very important application.

In tests made in some establishments we have used simultaneously the titaniferous pig and the alloy in the cupola, and the results were such a toughness combined with a remarkable hardness and strength of chill in car-wheels that it has justified the statements of some manufacturers as to the importance of these products in the iron industry, when better known. To obtain them cheaply—and we mean by that at such a price that their use would prove economical in view of the results secured—has been our aim.

We may remark here, that if the thickness of a casting can be diminished without impairing its strength—on the contrary leaving it stronger—the cost of the material which has secured such a result may well be compensated for and more by the advantages obtained.

We are continuing our tests along these lines for different establishments, and we may be justified in saying, as a conclusion, that if these tests and those carried on by outside parties, to whom we are willing to extend all facilities to make them, justify our claim, as those already made have done, that the importance of the metallurgy of titanium cannot be ignored or overlooked much longer, and that these titaniferous ores, as we have said at the outset, will constitute a valuable resource and reserve for the future, both for blast-furnace stock for the manufacture of pig-iron and for metallurgy in general for the production of valuable alloys. Titanium may be found to form alloys with other metals than iron, or with iron and other metals possessing special

and valuable qualities. We have had no trouble, by following our aluminum method, in making alloys of titanium and copper and titanium-iron, and other metals, alloys of which we are now engaged in studying the properties, some of which appear to be rather remarkable.

NEW YORK, April, 1902.

RECENT PROGRESS IN ELECTROCHEMISTRY.

A novel method for the production of calcium carbide is suggested by MM. Vulitch and d'Orlowsky, of Paris, the authors proposing as an alternative to the usual practice of heating a suitable mixture of lime with carbon, to first fuse the lime in an arc furnace, and then discharge the molten mass into an excess of heavy hydrocarbon, such as "masud," or other residue of petroleum distillation. The formation of the carbide occurs within the body of hydrocarbon, and the product possesses, as would be expected, some distinctive properties: it is loose and non-coherent, and is saturated throughout its mass with the hydrocarbon, which modifies its relations with water, rendering it practically non-hygroscopic. It is peculiarly adapted for the intermittent generation of acetylene, since it is not penetrable by water, and the evolution of gas continues only during the period of actual immersion. It is asserted also that it is free from phosphorus, which is eliminated by forming with the hydrocarbon volatile hydrides.

In Hall's improvements in electric furnace methods for the purification of beauxite, as will be recalled, the silicon and titanium are separated by reduction, and are collected in iron, either normally present or added in proper quantity. An additional patent issued to Hall, under date of June 3, 1902, deals with the utilization of this alloy as a basis for a metallic paint. An alloy containing about 60 per cent. of iron and 40 per cent. of one or all of the electro-positive metals mentioned, is brittle and readily comminuted; mixed or ground with oil it constitutes the paint of the patent.

The colloidal condition assumed by many metals under special conditions of precipitation is clearly a problem for the electrochemist, and when fully elucidated will undoubtedly throw additional light upon the mechanics of solution. Such metals as gold, silver, platinum, tin and mercury may be readily obtained in a form soluble in water, but separated therefrom by evaporation, freezing, or the addition of electrolytes. Subjected to the electric current they separate upon the anode, or if a diaphragm be employed, upon its negative side. In common with other colloids they are incapable of penetrating a porous membrane, and their solutions may therefore be concentrated by dialysis.

Colloidal silver is well known through the classic work of M. Carey Lea; colloidal gold has been studied by Zsigmondy, who prepared it by the reducing action of aldehydes upon extremely dilute hot alkaline solutions of chloride of gold; and colloidal mercury has been prepared by Lottermoser by reduction by stannous chloride. Gold, silver, platinum, cadmium and zinc have also been obtained in this form by Bredig by the action of a luminous arc

between metal wires in an extremely dilute solution of caustic potash. Dr. Carl Paal, of the University of Erlangen, has now prepared both gold and silver not only as colloidal solutions, but as measurably pure metallic products. The gold exists as bright scales of bronzy luster containing over 70 per cent. of the metal, and the silver as lustrous blue scales of above 90 per cent. purity. Both metals readily and completely dissolve in water—the silver with a bright yellow-brown coloration and the gold to the intense red solution of Zsigmondy. Both metals are precipitated by dilute acids, but in sharp contradistinction to the forms heretofore obtained the precipitates readily dissolve again in weak alkali.

The colloidal gold is prepared by pouring the chloride in concentrated aqueous solution into a heated alkaline solution formed by the treatment of albumens with warm dilute alkali; the solution obtained is dialyzed against water, precipitated by dilute acetic acid, redissolved in dilute caustic soda, and the metal recovered by slow evaporation. Colloidal silver is prepared in a substantially similar manner.—*Clinton Paul Townsend in Electrical World.*

VIRTUES OF THE PINEAPPLE.

The partaking of a slice of pineapple after a meal is quite in accordance with physiological indications, since, though it may not be generally known, fresh pineapple juice contains a remarkably active digestive principle similar to pepsin. This principle has been termed "bromelin," and so powerful is its action upon proteids that it will digest as much as one thousand times its weight within a few hours. Its digestive activity varies in accordance with the kind of proteid to which it is subjected. Filbrin disappears entirely after a time. With the coagulated albumen of eggs the digestive process is slow, while with the albumen of meat its action seems first to produce a pulpy gelatinous mass, which, however, completely dissolves after a short time. When a slice of fresh pineapple is placed upon a raw beefsteak the surface of the steak becomes gradually gelatinous, owing to the digestive action of the enzyme of the juice.

Of course, it is well known that digestive agents exist also in other fruits, but when it is considered that an average sized pineapple will yield nearly two pints of juice, it will be seen that the digestive action of the whole fruit must be enormous. The activity of this peculiar digestive agent is destroyed in the cooked pineapple, but unless the pineapple is preserved by heat there is no reason why the tinned fruit should not retain the digestive power. The active digestive principle may be obtained from the juice by dissolving a large quantity of common salt in it, when a precipitate is obtained possessing the remarkable digestive power just described.

Unlike pepsin, the digestive principle of the pineapple will operate in an acid, neutral, or even alkaline medium, according to the kind of proteid to which it is presented. It may, therefore, be assumed that the pineapple enzyme would not only aid the work of digestion in the stomach, but would continue that action in the intestinal tract. Pineapple, it may be added, contains much indigestive matter of the nature of woody fiber, but it is quite possible that the decidedly digestive properties of the juice compensate for this fact.—*The Lancet.*

Mining and Metallurgical Section.

[*Joint meeting of the Section and the American Institute of Mining Engineers, held Wednesday, May 14, 1902, at the Manufacturers' Club, Philadelphia.*]

The Beaumont Oil Field, with Notes on Other Oil Fields of the Texas Region.

By Robert T. Hill, Washington, D. C.

(*Concluded from p. 238.*)

THE GEOLOGY OF THE BEAUMONT FIELD.

The Coast Prairie is a belt of prairie land from ten to fifty miles wide which borders the Gulf of Mexico for nearly 400 miles from the Mississippi in Western Louisiana through Texas into Mexico. It is one of the newest made and least understood of our American geographic provinces.

This is a grass-covered constructional plain, newly reclaimed from the Gulf of Mexico. In general character it resembles very much the New Jersey flats of our northern coast, with which it has many features of age and mode of origin in common.

Topographically, it is an almost level plain, sloping seaward at the rate of about one foot to the mile; its interior margin rises scarcely 100 feet above the sea. It is impossible with present knowledge to delineate the interior border with exactness, for belts of timber constantly encroach upon it. Its almost level surface is broken by a few low drainage-grooves. There are deep drowned bayous in Louisiana and East Texas; but these become fewer and more faintly developed toward the Rio Grande.

No topographic surveys have ever been made of any portion of the Coast Prairie, and hence the slight irregularities of its contour are discernible only with difficulty. Until Captain Lucas's investigations, certain low elevations, which have since become the most important features of

the landscape, were hardly noticed. I allude to low swells or hills such as Spindle Top, which occur here and there, and now attract attention from their supposed relation to the occurrence of oil beneath them. These mounds or hills are in reality gentle swells.

Until the past decade this country, which is swampy in places and in its southwestern extension semi-arid, was considered good only for cattle-raising. For fifty years, immigration passed beyond it to the more fertile portions of the State. Prior to the recent oil boom, however, it was acquiring a great impetus through the development of rice-culture, and to-day it is one of the most active industrial sections of the Union.

Geology of the Coast Prairie.—The low relief of the Coast Prairie, the absence of extensive natural or artificial cuttings and the mantle of vegetation render difficult the study of the problems of its stratigraphy and structure. We know that this prairie is underlaid to an indefinite depth by a series of sea-muds and sands similar to the present marginal deposits of the Gulf. On a previous page I have given the geological series which should underlie the prairie, and called attention to the difficulty of classifying the later beds. These late Tertiary (Neocene) and Pleistocene formations which succeed the Frio clays of Kennedy (the top of the Angelina series), underlie the Coast Prairie, and contain the oil, have never been classified, and may be called the *X* beds until a definite classification is made. In addition to very recent alluvium and loam, they may include the formations described in Louisiana as the "Hudson" and "Grand Gulf." Paleontologists have also identified shells from the Galveston and Beaumont wells, which they have referred to the Miocene; but no geologist has ever identified formations of this age outcropping at the surface in the Texas series.

No proof has been obtained of the total thickness of the *X* beds nor the depth of the top of the Eocene Tertiary, beneath the Coast Prairie. In fact, not one of the drill-holes in the Coast Prairie, the deepest of which was the well at Galveston, Tex. (3,050 feet), has ever penetrated to it. Ac-

cording to the section of this well, there are 2,920 feet of such strata beneath the Texas Coast Prairie of Recent, Pleistocene and Miocene Ages.

Some sections have been published which convey an idea of the material of the unconsolidated *X* beds. They are composed almost entirely of unconsolidated material, which weathers into a mantle of soil. One section at Beaumont shows the strata down to the oil-bearing rocks. Another, of the deep well at Galveston, Tex., includes the equivalents of all the strata passed through in the Beaumont well, together with 2,000 feet of lower, and probably from 100 to 3,000 feet of higher beds.

A third section is that of the Louisiana Petroleum and Coal Oil Company's well, 1,230 feet deep, in Calcasieu parish, on one of two small islands in the marsh which forms the head of the Bayou Choupique. The section originally given by Hilgard is republished in the "Geological Survey Report of Louisiana" for 1899, page 25.

A fourth section is that of the wells at Belle Isle, given in the "Louisiana Geological Survey Report," 1899, Plate XXII.

Some information concerning the formation of the Coast Prairie, with a *résumé* of previous work, is found in a preliminary report of the geology of Louisiana, transmitted in November, but without date of publication on the title page (probably 1900). On the map accompanying this report, it is remarked that the distribution of the post-Eocene deposits is based mainly on previous surveys.

A few fragmentary data concerning the character of the formation have been given by Dr. Loughridge in the special report on cotton production for the Ninth Census; but, as a whole, the Neocene, Pleistocene and Recent formations immediately underlying the Coast Prairie are still unstudied and uncorrelated.

Several of these sections would lead the reader to infer that the bottom of the *X* beds had been reached when the bodies of salt, sulphur and gypsum were encountered, and that these materials are of Cretaceous Age. Evidence will be presented later to show that this may not be the case.

According to a special report by Hilgard for the Louisiana Geological Survey, the Five Islands are the erosion-formed outliers of a cretaceous ridge or backbone which traverses Louisiana from its northwest corner in the direction of Vermilion Bay; and many geologists have referred the salt and sulphur beds to the Cretaceous.

A sifting of all the evidence upon the subject affords no proof of the Cretaceous Age of the salt islands, which has been asserted solely on lithologic grounds, paleontologic evidence being entirely lacking. It is true that there is a change of material in several of the drill-holes, as, for instance, from the salt of the salt island and Damon's Mound, and the dolomite of Big Hill; but if these materials have originated by secondary replacement, as I maintain may have happened, they may be of post-Tertiary Age.

Structure of the Coast Prairie.—The Coast Prairie is topographically monotonous and so near to sea level, and the geological formations so unconsolidated and indeterminate, that there are no surface factors to enable one to determine the elementary features of structural deformation, such as the anticlines and synclines, which are so easily traceable in other regions where indurated rocks abound. Notwithstanding its apparent simplicity, however, there are some knotty problems in the underground structure of the Coast Prairie which present a peculiar exception to all the rest of the Coastal Pain. As already observed, the outcrops of lower and lower beds occur in succession from the coast inward. But this is not true of the *X* beds. There is distinct evidence that among these, newer beds overlap older formations, which do not outcrop at the surface anywhere in the Coastal Plain. Thus, Miocene fossils have been recognized in the Galveston and Beaumont wells where no formations of this age are known to outcrop anywhere at the surface. The stratigraphic unconformities noted by Kennedy between the Camden and Angelina series, and the Angelina series and the *X* beds, also have an important bearing on this question.

There is some evidence that the Coast Prairie overlaps conceal a line of serious deformation, which may be a sharp

fold, with an increased dip coastward, or a zone of faulting. The normal dip of the Eocene strata immediately west of the Coastal Plain is from 10 to 20 feet per mile. If this rate of inclination continued to the coast, these strata would be buried only from 500 to 1,000 feet. But, as I have shown, they are probably more than 3,000 feet below the surface, showing either a rapid change in dip to 60 feet per mile, or a down-throw fault.

If such faulting or deformation exists beneath the Coast Prairie, overlapped and buried by later surface formations, the fact is most important. I shall recur to it later.

The Louisiana part of the prairie is acknowledged to be a subsiding area, as attested by actual bench-marks, the drowned character of the bayous, and the circle of cypress growth on the swamps. I know of no actual previous observations bearing upon the isostasy of the Texas portion of the prairie. McGee, in a recent article in the *National Geographic Magazine*, assumes that it is likewise subsiding; but observations made within the past year lead me to believe that west of the Trinity River, at least as far south as the mouth of the Colorado—beyond which we know nothing—the plain is rising. Between the Trinity and the Colorado all the streams have new-cut channels, characteristic of rising land, while the Brazos is actually cutting down through its own alluvium at sea-level, and for many miles above its mouth.

In the generally monotonous monoclinal structure there are a few wrinkles or small swells, likely to escape the eye of even the trained observer, and yet of a character which may have an important bearing on the oil-problem. These are the circular and oval mounds already described, which were first recognized by Captain Lucas. When he pointed out Spindle Top Hill to me, my eye could hardly detect it, for it rises by a gradual slope only 10 feet above the surrounding prairie plains. I was still more incredulous when he insisted that this mound, only 200 acres in extent, was an uplifted dome. But Captain Lucas said that I would be convinced of the uplift if I could see Damon's Mound in Brazoria County. In August, 1901, I visited that place, and

then returned for a second look at Spindle Top, and was convinced, that if these hills are not recent quaquaversal uplifts, no other known hypothesis will explain them.

Damon's Mound is an elliptical hill, a mile or more in greater diameter, rising 90 feet above the surrounding level. Its profile is everywhere convex, and it is not a hill of erosion or of volcanic material. Furthermore, a bed of limestone follows the contour of its surface, showing deformation. The ascent of the plain will not carry the latter to the height of this mound for 100 miles interiorward.

Phenomena Accompanying the Oil in the Beaumont Field.— By studies and drill-sections of the Coast Prairie, the following facts have been developed:

(1) The oil is closely associated with the mounds occurring on their slopes or summits.

(2) The mounds are usually anticlinal or quaquaversal in structure.

(3) Most of the chemical phenomena of the Lucas group occur in all these mounds in varying proportions.

(4) In some localities, hot water has been struck below the oil.

(5) In the original Lucas well, the oil itself is hot.

The oil seems to occur, not in any definite, continuous stratum, but in spots of many strata, under varying conditions. At several places, notably Rockland, Saratoga and Sour Lake, it is found at the surface as maltha or asphaltum, impregnating spots in beds of sand, which are indurated by it. At Jennings, Beaumont, Sour Lake, and other localities, several—at Sour Lake, for instance, eleven—"seeps" of oil have been encountered.

Gas in immense quantities, and frequently under such pressure as to wreck the wells, has been struck before reaching the oil. This has occurred several times at Spindle Top, twice at Sour Lake and once at Velasco, where the destructive effect was terrific.

Sulphur and sulphuretted hydrogen gas occurs in intimate association with the Beaumont oil. In fact, the oil itself is said to contain from 1 to 2 per cent. of sulphur, and the fumes of sulphuretted hydrogen are strong in the vicinity of the wells.

Captain Lucas early noticed that sulphuretted hydrogen, escaping from the earth under certain conditions, deposited sulphur in crevises near the surface. Such phenomena he observed at Spindle Top before commencing his well. At High Island, Galveston County, work was temporarily suspended on a well-hole, and the orifice was stopped with hay, in order to prevent obstruction from débris. Afterwards, when this plug was withdrawn, the hay was found to be imbedded in a matrix of sulphur, undoubtedly deposited from the escaping gas. At Damon's Mound, Brazoria County, sulphur was found near the surface only in small joints and fissures; and a clay impregnated with it, used as an ointment by the Indians who formerly inhabited the coast country, was subsequently mined and sold as a medicine by a company of Americans.

Underground bodies of sulphur, associated with the oil by natural processes, have been found in many localities. The Calcasieu section of Hilgard shows at 540 feet in depth solid "sulphur rock," similar to that encountered at 1,040, feet in the Beaumont well. At Damon's Mound a bed of sulphur from 10 to 40 feet thick was encountered above the salt. Crystal of free sulphur also occur in a cap-rock overlying the Spindle Top oil.

The following is reported of the well bored by Boughton & Wynn for the Higgins Oil Company at Spindle Top. I cannot vouch for the correctness of the statement:

> "The drillers claim that the oil-pool struck by their well is 40 feet deep, and that the oil rests upon a bed of sulphur. After the oil was struck, the borers permitted the pipe to sink until it struck bottom, which it did at the distance of 40 feet. The drillers then claim to have bored 4 feet into a bed of pure sulphur."

This well is about 800 feet from the Lucas well.

The bodies of sulphur are probably a by-product of the formation of the oil, which, at Spindle Top, is not only highly saturated with sulphuretted hydrogen, but contains by chemical analysis from 1·5 to 3 per cent. of sulphur. It was Captain Lucas who discovered the relation between the sulphuretted hydrogen fumaroles, gas-springs and sulphur incrustations at the surface, and the bodies of subterranean

oil; and it was his belief in this association that led him to seek for oil on Spindle Top Hill.

The bodies of salt discovered beneath the hills of the Coast Prairie are of remarkable size, thickness and purity—notably those in Louisiana, and one discovered in within the past few months at Damon's Mound, in Brazoria County, Tex.

The salt islands of Louisiana were described by Captain Lucas in the *Transactions* of the American Institute of Mining Engineers before his discovery of oil at Beaumont.* These so-called islands, rising from 80 to 250 feet above the surrounding marshes of the Coast Prairie, are hills beneath layers of stratified clay and sand. They belong to the same group of topographic phenomena as Spindle Top Hill at Beaumont.

By sinking through the superstructure of sand and clay, Capt. Lucas located the salt-bodies and determined their horizontal extent, developing also the important fact that, though limited in diameter, they were of great depth—that of Jefferson Island having been penetrated for 2,100 feet without reaching bottom.

Another important fact pointed out in Capt. Lucas's paper was that the substrata of the southeastern part of Belle Isle, above and down to the rock-salt, were heavily impregnated with petroleum. Several calcareous strata containing sulphur were also encountered, suggesting to him that more thorough exploration might develop a sulphur-deposit like the great Calcasieu deposit, and showing the association of these three materials.

All geologists who have expressed an opinion have committed themselves to the theory that these salt-masses were originally deposited in the sea and covered with later sediments. Capt. Lucas also accepted this hypothesis. The theory as stated by Adams† was, that "near the close of the Cretaceous Period, beds of rock-salt and gypsum were evidently precipitated in the land-locked remnants of the retreating sea."

**Trans. A. M. I. E.*, xxix, 462 *et seq.*

†U. S. "Geological Survey," *Bulletin* No. 184, p. 49.

The sediments of the lagoons, which in former times, as to day, bordered the Gulf of Mexico, were undoubtedly very saline; but we have no instances at present to lead us to suspect or believe that there have ever been conditions for the accumulation, by surface evaporation in such lagoons, of the enormous thickness of salt now found beneath the Coast Prairie mounds of Louisiana and Texas.

These vast salt-bodies are intimate historic associates of the oil, and record the past location of the circulation of saline waters, which were transporting agents in the distribution of the oil.

Since studying the phenomena of the Beaumont field, the writer has gradually developed another hypothesis, namely, that these salt bodies are the result of secondary replacement in the strata through the agency of the ascending circulation of saturated briny waters, as elsewhere explained.

Still another interesting phenomenon is the occurrence of dolomite. The oil of Spindle Top is said to occur in a cavernous mass of this material. At Big Hill, Jefferson County, which is one of the most conspicuous of the mounds, the drill, after going down 300 feet, penetrated a mass of solid, coarsely crystalline dolomite, in which it continued to nearly 1,375 feet. At 900 feet a small seep of oil was struck in the dolomite. This would suggest, at first glance, that a boss of ancient crystalline rock had been encountered; but such is probably not the case, as I shall endeavor to show.

In only one well, so far as I am able to ascertain, has the hot water which would be expected to follow the oil been encountered. This was in the Sour Lake field, where, as I am informed by the owner, a heavy flow of hot salt water was struck at about 1,400 feet—a lower level than that of the "gusher" oil of that vicinity.

The fact that the oil in the original Lucas gusher had a temperature of over 110° F. is most important. This phenomenon seems to have been overlooked heretofore by those who have studied the field.

Explorations have shown the following downward series in the quaquaversal hills: (1) a matrix or overlay of the

typical Coast Prairie formations; (2) oil-phenomena, consisting of sulphuretted hydrogen gas, escaping superficially, and secondary deposits of sulphur in the strata through which the sulphuretted gas has ascended; (3) oil, mixed with considerable sulphur and sulphuretted hydrogen; (4) sulphur, as a precipitate or sediment of the oil; (5) sodium chloride and magnesian lime carbonate, as after-products of the oil; and (6) hot salt water, under great hydrostatic pressure.

GEOLOGICAL SOURCE AND DISTRIBUTION OF THE OIL.

The ablest geological experts and practical oil-men have found the conditions in the Beaumont field different in every detail from those of all previously discovered fields, especially those of Ohio, California, West Virginia and Pennsylvania. The magnificent work of Orton, in Ohio; White, in Virginia, and Lesley and others in Pennsylvania, is inapplicable in this field.

The writer, like other geologists, assumed at first that oil-deposit was more or less of the sheet or blanket type, and for a while proceeded upon that theory, until it was upset by experiments around Spindle Top. A year ago I was inclined to believe that the Beaumont oil was, like that of the Trenton, Berea and Corsicana fields, indigenous to certain strata. But we are unable to define and describe such strata; and all evidence now tends to disprove that proposition.

While science has said, frankly, "We do not know, but we shall learn," fakirs of every imaginable kind and well-meaning practitioners from other fields have given advice in abundance. The man with the divining-switch; the boy who could see underground streams blindfold in the night; the electrical indicator man; the Pennsylvania oil-driller who recognized Pleistocene and Recent gravels on the surface as identical with the Paleozoic conglomerates of his native State, and a host of quack-geologists, have reaped a rich harvest in this field through the foolish and fruitless expenditure of much money.

Before the discovery at Spindle Top, there was only one

man whose ideas—although not yet co-ordinated into a theory—approximately fitted the observed conditions. Of course I refer to Captain Lucas, who, in his explorations of the Coastal Plain, seeking successively salt, sulphur and oil, had observed the association of oil, sulphur, sulphuretted hydrogen gas, gypsum, dolomite and salt, constituting collectively what might be termed the oil-phenomena, representing a group of secondary products, as distinguished from the mother-strata or sediments out of which they had been produced. Moreover, so far as I am aware, he first pointed out the existence of anticlinal hills in the Coast Prairie and their connection with the oil-phenomena. Concerning the origin and geology of the oil, however, he presented no opinions.

Captain Lucas also attached much significance to certain surface-phenomena, indicating that the sulphuretted hydrogen, escaping upward, either acidulated the surface-waters or deposited incrustations of sulphur in the soil. He inclined to believe that the mounds themselves were in some manner the result of the gas-pressure; and I think he favored the notion of horizontal distribution along lines of strike.

AN EXPLANATORY HYPOTHESIS.

The writer has in mind an hypothesis, not hitherto advanced, so far as he is aware, which co-ordinates Captain Lucas' data and explains that which he omitted—the source and distribution of the oil salt islands, sulphur, sulphuretted hydrogen gas, and dolomite. The hypothesis is offered with hesitation, not as a final explanation, but in the hope that it may serve as a basis for discussion through which the truth may be reached. I think it fully interprets the Lucas group of phenomena, and accounts for the mystery of Spindle Top far more satisfactorily than any other thus far presented; and that it may also account for the independent origin of the sulphur, sulphuretted hydrogen and gypsum, regardless of their association with the oil.

The hypothesis is as follows: The oil- and salt-pockets of the Texas Coastal Plain are probably not indigenous to the

strata in which they are found, but are the resultant products of columns of hot saline waters which have ascended, under hydrostatic pressure, at points along lines of structural weakness, through thousands of feet of shale, sand, and marine littoral sediments of the Coastal Plain section, through which oil and sand are disseminated in more or less minute quantities. The oil, with sulphur, may have been floated upward on these waters, and the salt and dolomite may have been crystallized from the saturated solution.

The channels of these ascending waters may have been in places of structural weakness, such as fissures, which probably at one time continued to the surface, but may have been sealed by the deposition of the later overlapping strata now capping the oil-pools. Such features, when occurring under gentle anticlines, may explain the collection of oil beneath the surface in pools.

The following known data may be adduced in support of this hypothesis: (1) The absence, at the depth of the Beaumont wells, of any local sheet or stratum from which it is probable that the tremendous body of oil could have been generated; (2) the probable existence of nearly 10,000 feet of Cretaceous, Tertiary, Quaternary and Recent unconsolidated sediments beneath the surface of the Coastal Plain, as demonstrated by the deep well at Galveston, and studies of the outcrops farther inland; (3) the dip of these strata beneath the Coast Prairie at a low angle, from the interior coastward; (4) the oil disseminated in small quantities in many of these strata; (5) the existence of seven or eight distinct reservoirs of artesian water in this series of strata, at depths which increase coastward; (6) the fact, demonstrated by artesian wells, that the water becomes hotter and more saline with increasing depth, thereby increasing its capacity for the collection and flotation of oil; (7) the intense hydrostatic pressure in these water-bearing strata, which apparently continue beneath the Coastal Plain; (8) the fact that this water has risen in spots along lines of fissure which are probably later, and are capped by 1,000 feet or more of the still later strata of the Coastal Prairie.

The evidence of these statements is as follows: (1) Experiments at Spindle Top, Saratoga, Jennings, Sour Lake and Velasco show that the accumulations of oil sufficient to produce gushers are not indigenous to the particular stratum in which they are found, but have been collected there as a result of other causes. It is also certain that the oil occurs in underground pools, which are related to the supposed anticlinal mounds in the new-made Recent Coast Prairie.

The main supply of oil at Spindle Top averages 1,000 feet in depth, and may be in strata of Pliocene or allied Miocene Age. But that this stratum in which the oil occurs is not continuously impregnated with a widespread sheet is testified by the barren ground developed all around Spindle Top. Nor do the many drill-holes bored up to this date reveal even any formation in the upper portion of the Coastal Plain capable of generating the vast quantity of oil found at Spindle Top, whatever its origin. These oils are not associated with extensive beds of either plant or animal remains from which the oil might have been generated. At one place, Saratoga, where they outcrop, they apparently occur in ferruginous sands.

A faint trace of oil is usually encountered at from 400 to 600 feet in depth, throughout the entire three hundred miles from Damon's Mound to Jennings. This was probably the first "seep" oil struck at about 600 or 700 feet in the Lucas well, and has been encountered at many other places. It may be a local horizon; but it has not been found to be always underlaid by a great "gusher" stratum, or by any signs of such a thing. That there are shallow strata beneath the Coastal Plain which are oil-bearing is apparent; but the product of all of these put together would not supply one "gusher."

(2) The now classical section of the deep well at Galveston, only a short distance from Beaumont, shows that there are at least 3,000 feet of unconsolidated gulf littoral sediments of later age than the Eocene Tertiary.

Beneath this there is every reason to believe (from its outcrop to the westward and dip toward the Gulf Prairie) that there must be an additional 300 feet of Eocene Tertiary

sands and clays. Similarly, west of the Tertiary, and dipping beneath it, geologists have measured at least 4,000 feet of marine Cretaceous formations, also dipping directly beneath the Coastal Plain.

If all these strata do (and no evidence has been as yet presented to show that they do not) extend beneath the Coast Prairie, then we have beneath it at least 10,000 feet of Cretaceous and later sediments, known to be (with the exception of 1,000 feet of consolidated limestones) almost entirely composed of more or less littoral, terrigenous, bituminous and ferruginous clay and sand.

(3) The dip of the buried portion of the strata of the Cretaceous and Eocene series beneath the present Coast Prairie is evident from the minute studies of the outcrops of these strata toward the interior. The Cretaceous strata dip toward the Coast Prairie from 25 to 40 feet per mile, as shown with great minuteness in the author's monograph of the Cretaceous formations.* The dips of the Eocene Tertiary, from 30 to 10 feet per mile, are given in the various reports of the Texas Surveys. While no one can say positively that these strata are beneath the Coast Prairie, induction leads to no other conclusion, and absolutely no reason can be advanced to prove that they are not.

(4) Of the 22,000 feet of sedimentaries in the Texas section, all but less than 2,000 feet are unconsolidated clays and sands, which may be more or less bituminous. Some of the limestones are also bituminous. Oil or bitumen has been found in at least a dozen horizons of the section. The older or Paleozoic group contains one in the Ordovician, and two or three in the Carboniferous (as at Brownwood, and at Henrietta, in Indian Territory). Of the strata composing the later grand group underlying the Coastal Plain, there are five oil horizons in the Cretaceous: one in the base of the lower Cretaceous (at St. Jo and Burnet); one in the Del Rio clays at Austin; one in the Eagle Ford clays in Grayson County; two in the Navarro beds of Corsicana; several in

* "Twenty-first Annual Report of the Director of the U. S. Geological Survey," Part VII.

the Eocene—notably that at Nacogdoches—and several in the post-Eocene at Beaumont.

In two instances, in Texas, bituminous matter (asphaltum) is found in apparently indigenous beds of limeshell conglomerate. One of these is the shell-breccia bed of the Travis Peak formation at Port Mountain, in Burnet County; the other is the shell-breccia in the upper Cretaceous at Cline, from which the Uvalde asphaltum is obtained.

The oil of the Corsicana field and that of San Antonio is derived from the shales of the Upper Cretaceous. The same strata which produce oil at Corsicana would, if continued, probably be embedded at least 4,000 or 5,000 feet beneath Beaumont.

The strata of the Eocene Tertiary present every favorable condition for the generation of petroleum, whether this material be derived from the decomposition of marine organisms, as alleged by some, or from the hydro-carbons generated by vegetable matter, as believed by others. There are vast accumulations of both materials in Eastern Texas.

It is an interesting fact that asphalts and oils rich in asphaltum occur in terrigenous (land-derived) sediments of the nature, age and general character of the East Texas Eocene, around the entire perimeter of the Gulf of Mexico and the Caribbean Sea. The asphalts of Tamaulipas in Mexico, Vera Cruz, the Isthmus of Panama and Cuba, as well as the great asphalt-deposits of Trinidad, Barbados and Venezuela, all come from beds of this character.

The oil from the Nacogdoches well is derived from near the top of the lignitic formations (Claiborne beds) of the Eocene Tertiary, the position of which has been definitely ascertained by geological study.

The *X* beds (post-Eocene) of the Coast Prairie are apparently rich in oily spots.

If a drill-hole could be continued to a depth of 10,000 feet below Beaumont, it should encounter: First, the Nacogdoches oil-stratum; next, the bituminous shales of the Eocene; next, the oil-shales of the Corsicana field; next, the Eagle Ford (Colorado) bituminous shales; then the bituminous beds which furnish the asphaltum of St. Jo and Burnet;

and, finally, the oil-shales of the Carboniferous. None of these strata were encountered within 3,000 feet of the surface in the deep wells at Galveston, or in any of the wells of the Coastal Plain. Between the Eocene or Claiborne stratum of Nacogdoches and the uppermost Pleistocene stratum of Beaumont there are thousands of feet of gypsiferous clays and sands in which nature may now be distilling oil.

(5) That the strata dipping beneath the Coast Prairie contain many beds (reservoirs) of artesian water is proved by extensive records and observations. These horizons are fully described in the writer's paper on the "Underground Waters of the Black and Grand Prairie."*

(6) This water increases in temperature with depth and in its capacity for taking in solution the solvent salts, and for upward flotation of the oil gathered in particles from the various strata through which it passes in greatest quantity. The fact that the water increases in temperature and salinity is conclusively proved by a line of wells, 100 miles in length, between Comanche and Marlin, in the lower portion of the Cretaceous series. The same stratum which furnishes water at both places outcrops at Comanche and supplies good potable water at almost every atmospheric temperature. At Marlin, 100 miles eastward, this water comes from a depth of 3,200 feet, has a temperature of nearly 140° F., and is excessively saline and sulphurous. Should the rate continue from Marlin to Galveston, this stratum would be, at the latter place, nearly 1,000 feet below the surface, and intensely heated and saline.

(7) If the lowest water sands of the Cretaceous of Texas are embedded beneath the Coastal Plain, several thousand feet below their outcrop, they must be under tremendous hydrostatic pressure. Their water must ever pass upward, and would take advantage of any structural weakness in the overlying beds to do so.

(8) In the discussion of the geology of the Coast Prairie, I have given some evidence of the existence of a strong monoclinal fold or faulting beneath the Coast Prairie.

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*Twenty-first Annual Report of the U. S. Geological Survey, Part VII, Washington, D. C., 1902.

There is much evidence that the present and former Coastal Plains of Texas, marking the recedence of the old shore-line of the Gulf of Mexico from the Rocky Mountain Region to its present site, has experienced periods of pause, producing a series of concentric shore-lines, accompanied by faulting. It is a singular fact that in another part of Texas, adjacent to a region which was at one time a coast-line of the Gulf of Mexico, there existed such a line of weakness. The great Balcones fault, which the writer has frequently described, is of this character. It is very probable that, along the present coast-line, similar faulting took place in Eocene time, and that the evidence thereof has been obscured by overlapping of the Grand Gulf and later formations which veil the Coast Prairie.

It is also true that there are unconformities in the coastal section, such as the one described by Kennedy, which might have overlaid such fault-fissures in the Coast Prairie with more recent deposits.

If these deeply embedded water-bearing strata under tremendous hydrostatic head exist beneath the Coast Prairie, their waters would pass through any natural channels, such as fault-fissures, through all of the known sheet-oil horizons of Texas, except those of the Carboniferous formation. Such hot water would gather from the rocks, which are known to contain them, oil, salt, lime, sulphur and gypsum; and the oil gathered from these strata would be floated on the ascending saline waters.

If ascending columns of oil and water of this character should meet resistance near the surface, we could well conceive of the formation of such a pool as that beneath Spindle Top Hill. To produce such a formation, which would be practically like the end of a "mushroom" bullet, there must be resistance; and this resistance would naturally come from an impervious formation. The overlap of the upper *X* beds of the Coast Prairie, stopping the free exit of the water upward through the fault-lines, would produce such a resistance; and this overlap we believe to have taken place.

At any rate, should such a column of ascending water

with oil on top of it, reach a resistance near the surface, a subterranean pool of oil would result, such as we find at Spindle Top. Furthermore, the reaction which would take place in the column of water below the oil could theoretically account for all of the after-phenomena of the Coast Prairie mounds, such as the salt islands of Louisiana and Damon's Mound, and the dolomite of Big Hill.

It is a remarkably interesting fact that in the mammoth artesian springs of the Balcones fault-zone, between Austin and Del Rio, we have an analogous group of data showing the rise of subterranean water in spots along a line of faulting. Along this line great columns of water are now rising, not continuously, but in spots, like the supposed ancient artesian springs of the Coast Prairie. I allude to the series of springs at Austin, San Marcos, New Braunfels, San Antonio, Fort Clark and Del Rio.*

It is true that these waters do not bring any perceptible oil to the surface; but this is easily explained, since they pass mostly through limestones and non-bituminous strata. On the other hand, had they been, as the old structure of the Coast Prairie has been, overlapped by more recent formations, they would constitute columns of suppressed water like those we have theoretically supposed beneath the Coast Prairie.

A remarkable discovery has been made within the past few weeks, indicating the correctness, from a scientific point of view, of Captain Lucas' theory that the mounds were the *loci* of his groups of oil-phenomena, and supporting the hypothesis of ascending waters. In Brazoria County, Texas, some 350 miles west of Belle Island, Louisiana (almost as far as Philadelphia from Cleveland), the lonely mound known as Damon's Mound, similar to those of the Lousiana salt islands, rises out of the prairie. This has been penetrated, and proved to be an anticlinal dome similar to that of Belle Isle, with a similar stratigraphic section: Pleistocene sand and clay, with traces of sulphur in the surface-layers; oil;

* See "Geology and Underground Waters of the Edwards Plateau," 18th *Ann. Rep. U. S. Geol. Surv.*, Part II.

then sulphur; and, for its lower 700 feet, pure rock-salt, with occasional traces of oil, demonstrating the occurrence of the latter substance, but not in commercial quantities.

Now, the question arises, is Damon's Mound a fossil-oil hill, beneath which the oil existed but has passed away? If so, why not also the Five Islands, and other salt islands of Louisiana?

FOOD VALUE OF THE MUSHROOM.

The *London Lancet* says: "The notion has long been held that the mushroom presented the composition of animal flesh, which led to its being called the 'vegetable beefsteak.' It appears, however, that this conclusion has been based on some analysis made many years ago, when analytical methods were not so exact as they are now and when the chemistry of food was not so well understood. In one regard, at any rate, the mushroom does resemble a beefsteak—in that it contains practically the same amount of water. But the dry, solid constituents of the mushroom differ very materially in kind from the solids of meat. The most important difference is due to the rich proportion of proteids—the so-called flesh-formers—in meat as compared with the feeble amount in the mushroom. This fact, as ascertained by recent analyses, hardly justifies the mushroom being regarded as a 'vegetable beefsteak.' It may be a blow to the vegetarian, but he would have to consume at least ten pounds of mushrooms in order to gain the equivalent of a little over one pound of prime beef. Indeed, in the light of modern inquiry, there seems to be no reason for believing that mushrooms possess any greater food value than other ordinary fresh vegetable foods, and in many respects they compare unfavorably with them.

"Still, the fresh, tender mushroom is undoubtedly easily digestible, and as it contains carbohydrates, in addition to some proteid, it is obvious that it is of some dietetic value. This value is not comparable with that possessed by essential foods, such as meat, milk and eggs. The mushroom, however, contains an unusual proportion of potassium salts. Few will deny that the mushroom is an excellent adjunct to many dishes; it has an appetizing flavor, and this quality alone makes it dietetically valuable."

DANGERS FROM ELECTRICAL RAILWAY APPLIANCE.

George Westinghouse has pointed out certain dangers which, in his opinion, should be guarded against in the fitting of trains with electrical apparatus. Mr. Westinghouse says: "It is not very apparent how these dangers can be guarded against. A lifelong experience, however, in connection with safety appliances upon railroads has caused me to view the subject from quite a different standpoint from that usually taken, especially by inventors and promotors, and in some cases by manufacturers of electrical apparatus, who evidently dislike to emphasize the dangers attending the application of so much electrical machinery beneath the ordinary combustible

cars now generally in use and the utilization of which has been contemplated in order to keep down the total cost of installation.

"I believe a further useful purpose will be served by particularizing some of the dangers to be guarded against in the fitting of trains with electrical apparatus:

"(1) A great advantage of electric traction is the possibility of a much higher speed. This, however, while not extending the vision of the engineer in charge of the apparatus, will require a greater distance within which to stop the train.

"(2) When many tons of electrical apparatus are distributed beneath several cars of a train, and of necessity more or less loosely supported, and between which and the rails and roadbed there is but a small clearance, it is evident that much greater precautions will have to be taken than is ordinarily the case with the running gear of the present steamcars, derangements in which have often been the cause of accident.

"(3) Electrical apparatus supported beneath the car can develop, by means of a short circuit, heat-energy sufficient to instantly ignite cars of wood construction, and this has occurred repeatedly, notwithstanding the presence of safety appliances, intended to guard against such occurrences.

"(4) When a total wreck results from an accident (and experience has shown that accidents are inevitable, whatever the mode of propulsion) the debris scattered over the 'live' and other rails would render useless the ordinary circuit-controlling devices which may be located upon the cars. This emphasizes the importance of a non-combustible construction of cars."

A NEW INCANDESCENT ELECTRIC LAMP.

Osmium has the highest melting-point of any metal, viz., about 2,600° C., and it can therefore be used at a higher temperature than carbon in an incandescent lamp, making the efficiency correspondingly higher. The lamp was the invention of Dr. Auer von Welsbach, and the Auer Company, who are making it, will shortly be letting out lamps on hire. Owing to the rarity of osmium, it is found worth while to employ the metal remaining in the filaments after they have burned out. The chief difficulty appears to be the low resistivity of osmium. Owing to this, up to the present, lamps of 25, 35 and 50 volts only have been produced, and the smallest candlepower of a 35-volt lamp has so far been 40. The lecturer described experiments made with a 20-volt lamp at different pressures. At 20·5 volts the lamp gave 22 candle-power, and required 1·48 watts per candle. At 25 volts the efficiency rose to 0·99 watts per candle and the candle power to 46. At 30 volts the figures were 0·654 watts per candle and 99 candle-power; at 35 volts 0·487 watts per candle and 171 candle-power; at 40 volts 0·38 watts per candle and 275 candle-power; and at 50 volts 0·32 watts per candle and 460 candle-power. At this pressure the lamp burned out. A life-test was made on another lamp at its normal pressure. This lamp required 1·5 watts per candle at the commencement, dropped gradually to 1·36 and 1·32 watts per candle, and finished at 1·4 watts per candle after 1,100 hours. During this time the candle-power, which started at 14·7, rose gradually to 16·8 after 250 hours, and then dropped to 15 candle-power after 1,000 hours' use.—*Scientific American.*

CHEMICAL SECTION.

Stated Meeting, held Thursday, May 22, 1902.

A Review of Some of the Recent Literature of the Periodic Law.

By Robert Hart Bradbury,
Member of the Institute.

(1) The test of a generalization comes when research multiplies the number of facts which fall within its scope. If these new facts can be correlated by the hypothesis they will lift it to a higher level of authority and scientific utility. If not, various things may happen. If the data which cannot be explained by it are not numerous, a hypothesis may be retained unaltered for a long time, and the facts which do not fall into line be ranked as exceptions. Rigorously speaking, this is an illogical attitude, for a scientific law admits of no exceptions, but it is justified by practical reasons. It is often imprudent to discard one generalization until another is at hand which shall serve as well, or better, to arrange the data and point out the direction of further advance into the unknown. Again, further investigation sometimes shows that, after all, the supposed disagreement is unreal and that this hypothesis which has been questioned is still able to serve as a basis for the arrangement of all the data in its field.

The recent revival of interest in the inorganic side of chemical science has subjected the periodic law to a severe test. Data have accumulated with great rapidity and have produced divergent opinions with respect to the possibility of explaining them upon the basis of Mendelejeff's system. Even the advisability of retaining the latter at all has been questioned. It is the purpose of this paper to give an account of some phases of this discussion.

(2) *The Place of Hydrogen.*—Considering the importance of the element and the obviousness of the problem, the place of hydrogen in the periodic system has been the subject of surprisingly little discussion. As a rule, the books

content themselves with simply leaving it out of the table, or placing it by itself somewhere in the margin, and fail to face the problem at all. Nevertheless, the problem is a real one. Hydrogen is an element of a very peculiar physical and chemical character, and it must belong somewhere. But the task of placing it is by no means easy.

The field is narrowed at the outset by the *univalence* of the element.* The valence of most elements has been a theme of discussion—that of hydrogen, never. Not only is it constantly univalent itself, but it appears able to impose the attribute of constant valence on other elements, for variable valence toward hydrogen is unknown. Hence, there are only two possibilities. Hydrogen must belong in group I, at the head of the alkali metals, or in group VII, at the head of the halogens.

For the following reasons the head of group VII appears to be the more suitable position:

(1) The hydrogen molecule is diatomic, like F_2, O_2, B_2 and I_2. On the other hand Li, Na, R, Rb and Cs, like the other metals, form *monatomic* molecules.

(2) The numerical values of the atomic weights point to that conclusion. The difference between the atomic weights of consecutive members of the same vertical group is 15–20. Now F—H=18, which is entirely normal. But Li—H=6, which is unprecedented. Again, it will be shown hereafter that helium (He=4) must be placed in group VII. If, then, hydrogen is to be placed at the head of group I, there must be six elements whose atomic weights vary by such small increments that they can be inserted between H=1 and He=4. This is utterly anomalous, since the differences between elements horizontally consecutive are from ·5 to 3.

(3) The gaseous character and low boiling-point of hydrogen are precisely what we should expect of a lower homologue of fluorine, since, with the halogens, volatility increases with decreasing atomic weight. But from cæsium to lithium, melting-point and boiling-point rise and vola-

* Masson: *Chemical News*, **80**, 283.

tility decreases with decreasing atomic weight, so that we should expect a lower homologue of lithium to be more difficult to melt and to vaporize than lithium itself.

(4) The transparent non-metallic character of liquid hydrogen is a powerful objection to placing it in the lithium group. But with the halogens, color becomes paler with decreasing atomic weight and there is no objection to assigning to a colorless element the position of a lower homologue of fluorine.

(5) Lithium unites with hydrogen with well-marked combustion (Guntz). Such behavior from a metallic vapor toward another metal of the same group would be extraordinary. But from a halogen it would be normal.

(6) The similarity in the formulas of acids and salts, and the existence of positively charged hydrogen ions in solutions is an argument for classing hydrogen with the alkaline metals. However, acids are sharply distinguished from salts by marked peculiarities of chemical conduct. Chlorine and the other halogens substitute hydrogen in organic compounds without essentially altering the nature of the substance, and this is an equally strong reason for classing hydrogen with the halogens.

In spite of all that has been said it must be admitted that the place in Group VII is by no means satisfactory. The energetic union of hydrogen with fluorine is not at all what we should expect from two consecutive elements of the same group, though not entirely without analogy (oxygen and sulphur). The chemical conduct of hydrogen is not that of a halogen. And since chemical energy and non-metallic character increase greatly from iodine to fluorine we should expect hydrogen to be a still more violent non-metal than the latter, which, of course, is very far from being the case.

(3) *The Place of Argon, Helium and the Allied Elements.*— Upon the discovery of argon and helium, discussion of their relations to the periodic table arose at once. For a time it seemed that the table offered no place for them, and many thought that it ought to be abandoned or profoundly modified on that account. Some, taking the other horn of the

dilemma, held fast to the table and questioned the elementary character of argon, speculating about the possibility of its being an allotropic form of some known element (nitrogen) of a mixture of two or more species of monatomic molecules giving an *average* atomic weight of about 40. Still others adopted the very sensible suggestion of Piccini that these elements might, at least for the present, be left out of the table altogether. For to place an element in any part of the periodic table is to make certain more or less definite statements about its atomic weight, valence and chemical character generally. It is difficult to do this with elements which have no valence and no chemical character. It is even possible to question the propriety of speaking of the "atomic weight" of an element like argon. For the atomic weight is a chemical constant, determined by chemical methods, and the use of such methods is impossible with an element which forms no compounds.

Ramsay* came to the conclusion that there is a place for elements of zero valence in Group VIII, where they can serve as linking elements between the halogens and the alkalies. But if this is the case, there must be a whole vertical group of such elements, and this group should display similar numerical relations to the other groups. The search for such relations led to the discovery of three additional elements of the group.

The differences between the atomic weights of consecutive elements of the same vertical group is 16 to 20. Thus Ce — F = 16·5, S — O = 16. Further down in the table we have Mn — Cl = 19·5, Cr — S = 20·3, etc. Now Ar — He = 36, just as Cr — O = 36·3 and Ti — C = 36. Hence there should be an element between helium and argon, whose atomic weight should be about He + 16 = 20. If the molecules of this element are monatomic, its density should be 10.

After a long and laborious search, Ramsay finally discovered the missing element in the gases obtained by the fractionation of liquid air, and gave it the name of *neon*. At the same time he discovered two other gases—krypton

* "Nature," **65**, 161.

and xenon—which also turned out to be missing members of Group VIII.

The following little table will illustrate the function of these elements in the periodic system, and will show that they form a group whose numerical relations are very much the same as those of the other groups:

Group VII.	Group VIII.	Group I.
H (1)	He (4)	Li (7)
F (19)	Ne (20)	Nr (23)
Cl (35·5)	Ar (40)	K (39)
Br (80)	Kr (82)	Rb (85)
L (127)	X (128)	Cs (133)

It will be seen that these elements of zero valence and no chemical character form a natural passage from the strongly electro-negative non-metallic halogens to the strongly electropositive metals of the alkalies. It should be pointed out that this addition to Group VIII does not disturb the metals which have previously occupied that group. They still remain, exercising their linking function between the two halves of the long periods. This is a different function from that of helium and its allies, and therefore the great differences between these metals on the one hand and the helium gases on the other are not surprising. And besides, it is no new thing for elements profoundly different in chemical character to be placed in the same column of the periodic table. Witness the classing together of gold and cæsium, of manganese and fluorine, of chromium and oxygen.

The periodicity of valence finds clear expression in this classification of helium and its allies.* Thus:

The valence toward hydrogen	in Group IV	is 4
	in Group V	is 3
	in Group VI	is 2
	in Group VII	is 1
therefore, naturally,	in Group VIII	is 0
But the valence toward oxygen and electronegative elements generally	in Group IV	is 4
	in Group III	is 3
	in Group II	is 2
	in Group I	is 1
therefore, naturally,	in Group VIII	is 0

* Howe: *Chem. News*, **80**, 74.

(4) It will be noticed that the atomic weight of argon (40) is slightly higher than that of the element which follows it—potassium (39). This is a difficulty which is met with in at least two other cases. Almost all the atomic weight determinations of *tellurium* make it higher than that of iodine. The more cautious may still entertain doubts about the atomic weight of tellurium, and even of argon (on account of the impossibility of using chemical methods of purifying the element, or of furnishing chemical evidence of the fact of purity), but there is another instance, upon which there can hardly be any argument. If there is any truth in the transitional function of the triplets of metals in the eighth group, cobalt must precede nickel, thus—

Group VII.	Group VIII.	Group I.
Mn	Fe Co Ni	Cu

Yet the very accurate determinations of Richards leave no doubt that the atomic weight of cobalt (59) is higher than that of nickel (58·7). It is difficult to escape from the conclusion that an element may have a slightly higher atomic weight than one which follows it in the table. An interesting suggestion which Biltz has made upon this subject will be referred to below.

(5) This case of cobalt and nickel will serve to remind us of the fact that our conceptions of the transitional functions of the metals of the eighth group are more or less misty and unsatisfactory.* This is a matter in which precision of thought and statement are needed. For instance, iron, cobalt and nickel are transition elements between manganese and copper. Even if we restrict the statement to the free elements—which we have no right to do—there are difficulties; for instance, with respect to magnetic properties. But when we include the compounds in our field of view, it becomes exceedingly difficult to explain just what we mean by the transition.

Thus, since the group valence in the first group is 1, we should expect a transition or gradual variation in properties

* Locke: *American Chemical Journal*, **20**, 581.

from univalent manganese to univalent copper. But univalence is unknown with manganese and also with the three transition elements. The transition must therefore be between bivalent manganese and bivalent copper. But bivalent manganese and copper have no place in the periodic system which requires Cu^{I}, Mn^{I} and Mn^{VII}.* Going back to the next element, chromium, we find Cr^{II}, which exhibits, in a sense, the group valence. If we accept that as a starting-point and stability as a criterion we have the following: Cr^{II} (unstable) — Mn^{II} (stable)—Fe^{II} (unstable) — $\left\{ Co^{II}-Ni^{II}-Cu^{II} \right\}$ stable.

It is imposible to describe this sort of variation as transition.

If we adhere to trivalent derivatives we are even worse off.

Cr^{III} (stable)--Mn^{III} (unstable)—Fe^{III} (stable)—Co^{III} (unstable except in double salts) — Ni^{III} (almost unknown) — Cu^{III} (non-existent).

However, in discussing transition, we must not lay too much weight on arbitrary conditions. The instability of chromous and ferrous derivations is due to the accidental presence of oxygen in the air, while the instability of many other substances is a matter of temperature. As Ostwald has somewhere remarked, we are often unfair in our demands upon the periodic law. It is a good deal to require of any generalization, that it shall correlate the vast mass of collected chemical data, and we must remember in what an unsymmetrical way the data are grouped, especially with regard to temperature.

Thus, while we have an immense amount of qualitative and some quantitative knowledge of the behavior of various substances through a narrow range of temperature, yet our knowledge of their behavior at high and low temperatures is wonderfully fragmentary. It is altogether likely that if our knowledge was more complete we should have less difficulty in constructing a satisfactory generalization. Meanwhile, the fact of qualitative and, to some extent, quantita-

* The Roman numerals denote the valence of the element.

tive variation of properties with atomic weight is beyond discussion, and one of the obscurest problems of the table —the position of the inert gases—has been completely solved. With increasing activity in the inorganic field, and especially further research of the rare elements, will come more light.

(6) Finally, reference may be made to a suggestion of Biltz.* This is nothing less revolutionary than to drop the tacit assumption that each place in the table can be occupied by but one element and to admit that certain places can be occupied by groups. In such groups the atomic weights are close together and the similarity of the elements to each other is very great. Thus, to occupy the place at present assigned to manganese in group VII, Biltz suggests a group which he calls Σ Fe and which includes manganese, iron, cobalt and nickel. Among other simplifications, this gets rid of the difficulty about the atomic weights of cobalt and nickel. Other summations in the seventh group are:

$$\Sigma \text{ Pd} = \text{Ru Rb Pd}$$
$$\Sigma \text{ Pt} = \text{O}_2 \text{ Ir Pt.}$$

In group III, under indium, occur—

$$\Sigma \text{ Ce} = \text{La Ce Pr Nd.}$$

Researches now in progress among the rare earths will probably make possible the formation of other groups. The adoption of Biltz's suggestion effects a distinct simplification of the system, though not so great as might be inferred from a casual inspection of his table. Biltz's paper is clearly and concisely put and is decidedly worth reading. It is not likely, however, that his idea offers a final solution of the problem.

CENTRAL MANUAL TRAINING SCHOOL,
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* *Berichte*, **33**, 562.

The "Series-Vapor" and "Heat-Waste" Engines, as Supplementary to Single-Vapor Engines.

By R. H. Thurston,
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Progress in the evolution of thermodynamic systems of production of energy through the employment of the heat-motors has always been and always must be gained by application of certain definite and simple principles:

(1) The thermodynamic efficiency of the cycle employed must be made a maximum, and mechanical efficiency must be made as high as possible.

(2) Wastes must be minimized.

The thermodynamic efficiency of energy-conversion in the heat-engine in practice has always been and always must be improved by increasing the temperature-range of the cycle found to have best form for practical employment. In the steam-engine, this extension of that range is and always has been effected by raising the temperature, and incidentally the pressure, of boiler-steam. It has never been found practicable, as yet, to extend that range by depressing the lower limit of temperature of a diabatic expansion; hence great losses have been submitted to on that side of the temperature-range adopted on which most may be gained by a stated variation. It is more profitable to extend the range downward than upward, and neglect to so extend the lower portion of that range produced greater waste than similar loss of possible extension at the top. The waste-heat of the steam-engine is thus serious, and a "waste-heat engine" is more important than the imposition of higher temperatures and pressures, and of another cylinder in series to operate at the elevated pressure and temperature. In the gas-engine the upper limit is enormously elevated as compared with the steam-engine; but, unfortunately, the lower limit is also elevated and the various wastes increased; so that, as yet, the gas engine

fails to approximate its ideal even as closely as the steam-engine. It also needs to be supplemented with a "waste-heat" engine, and even more than any steam-engine.

The wastes, other than thermodynamic, are provided against by various expedients, more or less effective, which are constantly being improved upon, but which need not be here discussed further than to remark that the indications are that progress in their use seems to fully keep pace with that increased need which comes with increasing temperature ranges and improved thermodynamic efficiency.

"Possible improvements in the thermodynamic action of the steam-engine and its class of ideal heat-engines may occur in either of three principal ways:*

"(1) Improvements may be effected by change of type-cycle.

"(2) Improvements may occur through changes in the form of the cycle, without altering its distinctive characteristics.

"(3) Improvement may possibly be produced by change of working fluid.

"In illustration: Should it prove practicable to modify the operation of the steam-engine in such manner as, actually or in effect, to transform the second of the Rankine cycles—as produced in the regular working of the machine through the use of the steam jacket upon a metallic cylinder—into the first, that involving the use of a non-conducting cylinder, this change of cycle would usually, even in the thermodynamic case, effect a gain of above 10 per cent. Could still further improvement be made by converting the cycle, by change of construction of the machine, into that of Carnot, a further gain of 5 to 10 per cent. would be produced; these gains increasing with increasing ranges of pressure and temperature.

"Changes of the cycle itself may be of advantage when they involve increased temperature and pressure-range; when they insure more nearly adiabatic expansion; when they produce variations in the direction of approximating

* "Manual of the Steam-Engine," R. H. T.; Vol. I, p. 916, *et seq.*

better forms of cycle, as when compression, in the common cycle, is made to approximate the action of that part of the Carnot cycle, or when purely "cushion-steam" is reduced in quantity by reduction of clearance and 'dead spaces.'

"Changes of working fluid by substitution of ether, carbon disulphide, petroleum vapor, or other, for steam, have been seen to give in some cases special opportunity for securing increased efficiency by adapting the working substance to the desirable or practicable working range, for either temperature or pressure, while these advantages must be weighed against the usually unquestionably serious, sometimes obviously fatal, practical objections to their use, on the score of cost or of danger, or both.

"Multiple-fluid engines, of which the 'binary-vapor engine' is an example, are constructed with the object of extending the thermodynamic limits of adiabatic expansion and compression, and the intervening range of temperature, beyond those which are met with in a heat-engine in which a single working fluid is employed. The upper thermal limit is practically limited, in steam, by the impracticability of safely controling the accompanying high pressure, and, in fluids like air, by the difficulties of controling temperature at perfectly controlable pressures. The upper limit of available pressure does not, in any known fluid, coincide with the higher limit of safe and available temperature. To secure the high values, thermodynamically and dynamically, of the measure of maximum efficiency $(T_1 - T_2)/T_1$, the range, $T_1 - T_2$ must be carried as high and as low as the environment of the machine will permit. This may be accomplished, in some cases, by the adoption of a working fluid which may be employed at the higher limit, and of another which may be used at the lower limit, rejecting the utilized heat of the one into the other, in such manner as to produce cyles in series, of which the adjacent thermal lines shall be coincident.

"In such engines the construction and arrangement of the working cylinder is the same, in general purpose and arrangement, as in a multiple-cylinder steam-engine of the compound or triple-expansion type; except that in the latter

a single working fluid is employed, with cycles in series, transferring the heat and its vehicle, the fluid itself, from cylinder to cylinder between the higher and lower limits; while, in the multiple-fluid engine, heat only is dropped, step by step, transferring it from one fluid to another, cylinder by cylinder. Thermodynamically, the multiple-cylinder and the multiple-fluid engines are identical. Since the gain of one degree in the range of temperature worked through has more value at the lower than at the higher limit, the introduction, at the lower limit, of working-fluids more volatile than steam, to utilize the rejected heat of the exhaust, now wasted in the atmosphere or the condenser, has especial interest for the engineer. It is further to be noted that, in the multiple-fluid engine, each cycle is necessarily isolated and its working fluid continuously circulated. Surface-condensation thus becomes an essential feature, and each condenser is a recipient of heat from the working cylinder next above in the series, and a source of heat for the element next in order. Each working fluid constitutes the source of heat-supply for its own cycle and the refrigerating fluid for that next above.

"A multiple-vapor series should evidently consist of fluids of which each will have a boiling-point under a good and manageable pressure, at or below the temperature of the condensation of the fluid next above it in series, and a good mean effective working pressure between that point and the temperature and pressure of its own condensation. The latter temperature should be that of the high-pressure boiling-point of the next lower substance in the series, or above it. The uppermost element of the series should have a manageable pressure at the lowest practicable temperature of vaporization. The lowest in the series should have a condensing point, or boiling point, somewhat above the temperature of the condensing water, and at that point its vapor should have the least useful pressure. If choice is further allowed, under the circumstances practically controling the case, the series should have a fairly uniform distribution of the series of pressure-ranges, in order that a division of work as nearly as possible uniform among the

cylinders in series may give the desired work-distribution on the crank-pins of the engine."

"*Series Engines*" *and* "*Series-Vapor Engines*" are two classes of constructions which are thus denominated by the writer as distinguishing the two cases in which—as in the multiple-cylinder engine, illustrating the one class, the working fluid is worked in two or more cylinders, in series, as in the "heat-waste engine," illustrating the other class, series of working fluids are worked in a corresponding series of engines—a "cascade effect," as the French sometimes call it, is secured, through which, in the one case, the internal wastes of the engine are reduced by restriction of the expansion in a single cylinder and, in the other, the endeavor is made to secure a better adjustment of temperature and pressure-range to a common maximum; both being expedients to attain a higher thermal efficiency than can be obtained by the simple engine with its single fluid and in which the working fluid has an upper limit of temperature, which is fixed far below that which might otherwise be attained by the fact that its corresponding pressure has reached a limit due to danger, difficulty or cost of control; while its lower temperature limit is also restricted in value by the fact that the fluid, long before the limit is attained, reaches so low a tension as to be useless for thermodynamic action, the mechanical efficiency being thus made a vanishing quantity.

The "multiple-cylinder engine," or the "series engine" with the single fluid, does not modify this fact of an uneconomical adjustment of the temperature and pressure-limits of the single-fluid engine, although it does give great advantage, often, in permitting the extension of the process of thermodynamic transformation within the narrow range of practicable operation of the single fluid. The "series-vapor engine," on the other hand, enables some choice to be made among available working substances and in such manner as to permit at least crude adjustments of temperature and pressure-limits to a common and maximum working range, increasing the thermodynamic and the mechanical efficiency and their product, often, very greatly.

There are in all heat-engines two efficiencies, of the several in series between fuel and useful work, which are affected by this variation from the common type of machine. The efficiency of the machine as a heat-engine, its thermodynamic efficiency, is increased by any device which shall make it practicable to prolong the expansion of the working stroke throughout the full temperature-range between boiler and condenser, or to secure further approximation than is now commercially possible. The mechanical efficiency of the machine is improved by any device which may make the work of friction a smaller percentage of the total indicated work of the machine, thus enhancing the useful work and the total efficiency of the engine. Thermodynamic efficiency is promoted by increased ratio of expansion and mechanical efficiency is improved by any increase in the mean effective pressure of the working fluid at any stated ratio of expansion at any given temperature of the expanding fluid. There is no thermodynamic limit to expansion in the steam-engine, in the ideal case, short of the temperature and the vapor-pressure of the condenser; but there exists a commercial and practical limit at the point at which further expansion would return a gain, in value of increased power, less than the loss accompanying the gain, due to enhanced costs of production of that added power. The sources of this compensating loss are heat-transfer without performance of work and, outside the thermodynamic operation, excessive additional wastes by external conduction and radiation and added wastes of work through increase of the friction of engine by a necessary enlargement of the machine to accommodate the increased volume of the working fluid, while the mean effective pressure is diminished with similar result. When the mean effective pressure upon the piston approximates that which is required to move the engine without load, all power-production involves a waste of its full cost. When extension of thermodynamic range adds less value in work usefully available than it loses through increase of the heat-losses of the engine, further attempt to increase the thermodynamic efficiency produces a net loss to the full amount of outgo in the extension of the expansion-range.

If a fluid can be employed in a secondary heat-engine which is less subject to what is technically known as "cylinder condensation," and one which, at the temperatures of the lower range of pressure in the steam-engine during expansion, has a markedly higher vapor-pressure, it is evident that the new fluid would be available as an accessory to the primary working substance and its use would both reduce non-thermodynamic wastes of heat and, by increase of the mean effective pressure at the lower limit of temperature-range, save friction losses; thus both decreasing expenditures of heat and increasing the relative quantity of dynamic energy at the work-point.

There are some reasons for the belief that other substances are at once less subject to extra-thermodynamic wastes than is steam, and capable of furnishing comparatively high mean effective pressures at the low temperatures of the terminal portion of the expansion line. These fluids are practically available for use in the binary vapor-engine, and some have occasionally been thus employed.

The earliest writer to discuss this subject from the point of view of the modern engineer was probably Cotterill, who in his admirable treatise of the thermodynamics of the steam-engine calls attention to the fact that there exists an opportunity to utilize lower temperatures than those which fix the lower limit with the transformations of the steam-engine, and that this limit may be exceeded by the difference between it and the temperature of the condensing water, approximately; while the extended range offers a means of large gain. He further shows the advantage of replacing the condensing system in the steam-engine by a secondary engine in which a more volatile working fluid is employed, and thus pressures are rendered available at the same low temperatures which are in excess of the atmospheric pressure throughout the range of action of that element of the binary machine. This writer, the most original and sound student of the heat-engines of his date, states the desirability of adapting the working substance to the range of temperature through which the fluid is proposed to be worked, and indicates the necessity of employing gas-engines for tem-

peratures exceeding those now attained by the steam-engine, and volatile fluids for temperatures between those of the condenser of the steam-engine and of the condensing water, or even, probably, from the boiling point of water downward; the use of the condensing system, with its liability to inward leakage of air, and the various other objections to its employment, being thus evaded in part or wholly. These fluids, however, necessarily involve the employment of a closed system, and this in turn compels the use of surface condensers and vaporizers, and of an equally essential system of pumps for transfer of the fluid from the lower to the higher pressures, these elements of construction often proving no less obiectionable than the familiar condenser and air-pump and the circulating pump of the steam-engine.

The Fallacy of the Argument in favor of volatile liquids based upon their low "latent" heats is shown by computing the heat required to produce similar volumes of vapor with the various fluids from their liquids when having common initial temperatures. Thus, to produce a cubic meter of steam and of petroleum vapor employing a common mineral oil consisting of the hydrocarbons C_8H_{16} and C_8H_{18}, and at six atmospheres pressure would demand, respectively, 2,082 and 2,460 calories, while with alcohol the figure becomes 2,390.* Thermodynamically, all have similar efficiencies under similar thermodynamic conditions, and their relative values in practice depend, as elsewhere shown, upon the relations of temperature and of pressure-limits to each other and to pressures and temperatures external to the thermodynamic cycle; while the relative sizes of engines and boilers required for any stated engine-power, the cleanness and convenience of use of the fluid, its costs and safety, all influence the choice, usually vastly more than thermodynamic relations. The special adaptation of the fluid in question in any case to the special use in view is the real matter for discussion and decision by the engineer, rather than any thermodynamic question, as a rule. Thus we find ammonia adapted for use where, in any special case, it is desirable to

* J. Heinz: *Abs. Proc. Brit. Inst. C. E.*, p. 56, 1902.

avoid the employment of a condenser. The petroleums may perhaps be found to excel in total efficiency in some cases, as notably with small powers, through their oily nature and non-conductivity, permitting reduction of internal waste by condensation in the working cylinder. Ether superheats during adiabatic expansion, and this may prove an advantage, practically, in the maintenance of adiabatic expansion in the cylinder, while its volatility makes it a promising secondary fluid in the binary engine; especially as, in common with all very volatile liquids, this volatility makes direct heating, as in the boiler, troublesome and sometimes possibly dangerous.

Cotterill, and also the writer, long ago recognized the fact that it may prove possible to find a secondary, if not a primary fluid, with the use of which the now serious loss by cylinder condensation in the steam-engine may be considerably reduced.

This author finally remarks: "Mr. Willans has shown that in a non-condensing engine, with a boiler-pressure of about 180 pounds, the consumption of steam need not exceed 18 pounds per horse-power per hour. Now, the range of temperature here little exceeds 150°, and is, therefore, no more than that between 212° and the average temperature of the atmosphere in our climate. Thermodynamic science tells us that, if properly utilized by a suitable working fluid, this is worth as much as the same range above 212°; and it must, therefore, be practically possible to double the horse-power with the same consumption of steam, thus reducing the consumption to 9 pounds."

The question of utilizing the lower ranges of temperature now unavailable with the steam-engine is evidently no less important than the extension of the range upward. "All known engines are very imperfect in consequence of its neglect."*

Willans' figure for the non-condensing engine has since been reduced considerably and the condensing engine, with which, in fact, the series engine is properly compared, has

* Cotterill, p. 368.

made its record of about 10 pounds with moderately superheated steam, and the little quadruple-expansion engine of the Sibley College laboratories has, with pressures of 300 to 500 pounds, brought down the figure to about 9½ pounds per horse-power hour. Utilization of the hitherto wasted temperature range should bring the record considerably lower still, perhaps to the limit anticipated by Josse, 6·5 to 7, for now usual boiler-pressures. This economy could only be attained, without the utilization of these low temperatures, by carrying the boiler-pressure upward, in utilization of a higher range, to 1,000 pounds or more. Combining the two movements should give about 5 pounds.

The Thermodynamic properties of this class of substances may have, in some cases, important bearing upon their availability as working fluids in heat-engines, whether simple or of the multiple-fluid class. The energy-distribution, where heat is supplied to such a substance in the cycle of the vapor-engine, is exhibited in the general equation of Rankine:

$$U = C J [T_1 - T_2 (I + \log. T_1 / T_2)] + (T_1 - T_2) / T_1 . H_1;$$

where U measures the work of the cycle, C specific heat, J the value of the mechanical equivalent of heat (in British measures, 778), T_1 and T_2 the maximum and minimum temperatures of the cycle, and H_1 the latent heat of vaporization (in foot pounds, if in British measures) and at the higher temperature. The cycle here assumed is one taken as standard by Rankine and Clausins, in which no compression occurs but in which expansion is complete to the back-pressure at T_2. This is similar to the cycle of the usual forms of vapor-engine; although, in the latter, expansion is seldom complete. This case and cycle will serve our purpose best.

In this expression, the second term of the second member measures the heat transformation, with complete compression, in the Carnot cycle. The first term of that member obviously measures the work gained by suppression of compression. The gain is, however, as obviously paid for by a more than proportional heat-supply, since the Carnot is the

most efficient of all cycles in use in the heat-engine of any class.

It is at once seen that the work of the cycle, up to the point of commencement of expansion, is performed by the latent heat, H_1, of vaporization. The quantity of work which may be performed per unit of weight of the working fluid is thus largely dependent upon the magnitude of the quantity of energy stored in this form during the period of vaporization. It is further seen that the latent heat is transformed in this cycle with the highest possible efficiency; while the sensible heat, which finds expression in the remainder of the work-measure, is less efficiently utilized. It is thus evident that, other things equal, the larger the amount of vaporization of latent heat, and the more completely the cycle depends upon that store of energy for its work, the better the thermodynamic effect.

It is a matter of observation and experience, as well as of direct experimental determination, that the volatile fluids have small measures of latent heat of vaporization, and that the lower this value the more volatile the substance and the higher its pressure at a stated temperature of vaporization. A practically important fact results: that the volatile substance must be supplied in larger quantity per unit of work performed and the weight per horse-power hour increases with the diminution of this latent heat if the fluids compared are in other respects physically similar, the working cycle also being the same in kind. Water, the most common and least costly of working fluids, is thus that which stores most heat per pound and which requires the least quantity per unit of work performed.

Again, it is found that the volatile fluids, because of this lower storage capacity for heat, fluctuate most seriously with varying heat-supply at the furnace, and in some proportion to their volatility. They lack the large pressure-regulating power possessed by the water in the steam-boiler. The enormous fluctuation of pressure in the working cylinder of the engine in which the volatile substance is employed, as compared with such pressure-changes with water and steam, compels great precaution, in design-

ing both the engine and its boiler, to meet such possible dangers, and in operation. This danger is probably less where the vaporization is effected by the rejected heat of the primary engine than where produced by the direct heat of the fuel. Experience only can determine just how far this involves insurable risks.

The common, but perhaps not remarkable superstition among the ignorant, that all latent heat constitutes a waste and that this fact in itself gives volatile fluids thermodynamic advantage, has no foundation. In the steam-engine, for example, under usual conditions of good practice, this latent heat supplies by far the largest part of the work. On the other hand, the perfect gas, with its zero of such latent heat, may also be worked in the Carnot cycle with all the efficiency of substances having large vaporization latent heats. In this case, the utilized heat, however, is the *latent heat of isothermal expansion;* it is, after all, a latent heat. Latent heat, in either the one or the other of these forms, must be utilized to insure maximum efficiency of the cycle and highest possible economy in the engine, and the larger the proportion of latent heat so utilized the greater the work-effect per unit of cost and the better the heat-engine.

Clausius calls this latent heat "work-heat," since it is the measure of heat expended directly in the performance of the work of molecular displacement. It may be called "work-heat" very properly in another sense; it is the measure of the heat which is mainly the source of work by thermodynamic transformation. Thus, in the steam-engine, with steam at 75 pounds pressure, by gage, and a temperature of about 320° F., and with a condenser at 100°, the difference in sensible heat amounts to about 80,000 foot-pounds; but the latent heat of vaporization is the equivalent of about 690,000 foot-pounds, and the store of thermal energy is thus seen to exist mainly in the form of the potential energy of latent heat of vaporization, only about 12 per cent. of the total being in the form of sensible heat. Were the steam-engine, in this case, to utilize only the sensible heat, but to operate in the perfect-engine cycle of

Carnot, it would demand about 90 pounds of steam per horse-power hour; whereas, the actual engine of good standard practice is expected to call for not more than one-sixth that amount, the ideal engine of similar cycle demanding but about 8 pounds. (*Man. St. Engine;* Vol. I, p. 437.) The source of the energy of heat-transformation in the steam-engine is thus mainly the latent heat of voporization, the rightly named "work-heat;" it provides about 90 per cent. of the total.

The quantity of heat stored in the working fluid, in the perfect-engine cycle is always, and whatever the fluid, the latent heat of expansion from minimum to maximum volume during the period of storage, *i. e.*, that of expansion of a gas isothermally, but under varying pressure, or that of vaporization of a liquid, also isothermally, but under constant pressure. Since the requirement of maximum efficiency is introduction of heat at a maximum and a constant temperature and its rejection at a minimum and constant temperature, it is evident that positive work only is the result of the introduction of this heat, and that it is therefore all latent heat. Similarly, the rejection of heat at the lower limit of temperature and expansion-ranges indicates negative work, and only work. In neither case does change of temperature occur and in neither case, therefore, is sensible heat transferred.

The fact that the quantity of potential energy in store in the substance as its so-called latent heat of vaporization is not in any sense a measure of the cost of power-production in the perfect-engine cycle of a stated temperature-range, whatever the working fluid, is exhibited graphically in the accompanying sketch in which *a b c d* is, it may be assumed, the cycle of Carnot, with a substance—purely hypothetical, of course—capable of accepting variable quantities of "latent" heat.

During the production of whatever vapor, the temperature and the pressure alike remain constant and, necessarily, all heat supplied the fluid must be converted into work, internal and external, and this constitutes the misnamed quantity "latent heat." Should this or another

substance receive heat in this manner to the extent indicated by *a b'*, one-half *a b*, it is evident, first, that one-half the work would be performed in the cycle, and, secondly, that just as large a quantity of the substance would be required to perform it. The amount of both heat and working fluid would thus be determined by the extent to which the substance should be capable of absorbing "latent" heat. Thus the quantity of fluid circulating per unit of time will be in the inverse proportion of its quantity of latent heat of vaporization, other things equal; while the efficiency will obviously remain unchanged and absolutely independent of the nature of the working fluid

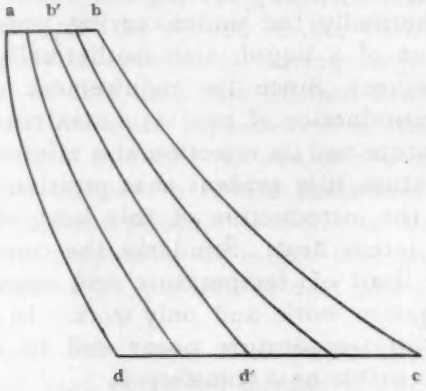

FIG. 1.—Work and latent heat.

and solely dependent upon the temperature-range of the cycle.

This is also perhaps as well shown thus: The work of the perfect-engine cycle is measured by the quantity

$$U_1 = H_1 (T_1 - T_2) / T_1.$$

Heat of vaporization, H, is supplied and it is utilized thermodynamically to the extent measured by the Carnot factor, range of temperature divided by the maximum absolute temperature. The latter is the efficiency of the cycle, the former factor the measure of the quantity of heat in action, as elsewhere stated; while the product is the measure of work performed at that efficiency per unit

weight or volume of working substance. With all fluids, the power delivered being constant as demanded by the engineer, the continued product of the latent heat, the efficiency and the number of cycles must give that measure of work.

Carnot's dictum regarding the thermodynamic identity in efficiency of all substances working in the perfect-engine cycle is plainly not applicable to comparisons of working substances where other cycles, less perfect, are adopted. Thus, a study of the form of the expression for the efficiency of the fluids worked in the Rankine or the Clausius cycle will show that the numerical value of the efficiency depends upon a function which involves both the heats of vaporization and the specific heats of the fluids. With variations of these constants, even with the same cycle, therefore, it may prove that two substances compared may give different efficiencies in a common cycle, although these differences are probably seldom important in practice. The differences which affect the extent to which initial condensation of the working fluid at the opening of the supply-valve, as, for example, between the oily and other substances, or between the steamlike and the etherlike, are probably much more important as affecting a choice of fluid; in other words, in any given cycle, with a stated temperature-range and fixed form and proportions, it is not probable that, in the ideal purely thermodynamic case, any important differences will be caused in the measure of its efficacy by change of working substance; but it is very probable that, in the real case, with its various sources of waste, thermally and dynamically, and varying relation of thermodynamic action to total energy supplied, there may be found sensible differences in the values of such substances and possibly sufficient differences in some instances to justify the selection of one in preference to others under special conditions of operation and of costs.

Hitherto, however, although the matter has been very often discussed, and both engineers and physicists have investigated the question very carefully from the point of view of theory, the ultimate deduction is still uncertain.

But it has been the common verdict of both engineers and men of science that, on the whole, steam is the most desirable single substance.

The conclusions of engineers generally, as well as of thermodynamists, have come to agree with those of Hirn, as expressed in his discussion of the heat-motors in his treatise on thermodynamics.* Hirn remarks:

"When one has clearly in mind the conditions of the problem, *i. e.*, to secure the largest practical return from the greatest temperature-range possible; and when, imbued with this principle, one glances even superficially over the tables of temperatures and tensions of various fluids, one becomes promptly convinced that the choice of the fluid to be employed, far from being a a matter of indifference, is of the greatest importance. Condemned by force of circumstances to utilize but a small fraction of the available temperature of the furnace, we should at least seek to make that fraction as large as possible. Contrary to the general opinion, there are fluids which, having moderate pressures at elevated temperatures, might, if their chemical and physical properties would permit, serve our purpose. Liquids and saturated vapors having high tensions at low temperatures, such as ether, carbon-disulphide, etc., should be definitively excluded from the form of generator exposed to the direct action of the fire, and these can serve only in the utilization of low temperatures, the wastes of the thermic motors. And this is true without reference to the dangers which usually accompany the industrial employment of such substances. At 120° C. (248° F.) sulphuric ether has a tension of 10 atmospheres; a pressure accepted as the limit in the locomotive. Water only attains this tension at a temperature of 180° C. (356° F.) and we may utilize 60° greater range of temperature with the latter.

"If, after this very clear and yet superficial study, we pass to a more minute examination of the subject, we finally recognize the fact that in the choice of a liquid we are ultimately led to that which, at present at least, is found to

* "Theorie mecanique de Chaleur," T. II, p. 11.

be unique. It is that which nature, fortunately, has everywhere placed at our service."

The Characteristics of the volatile as contrasted with

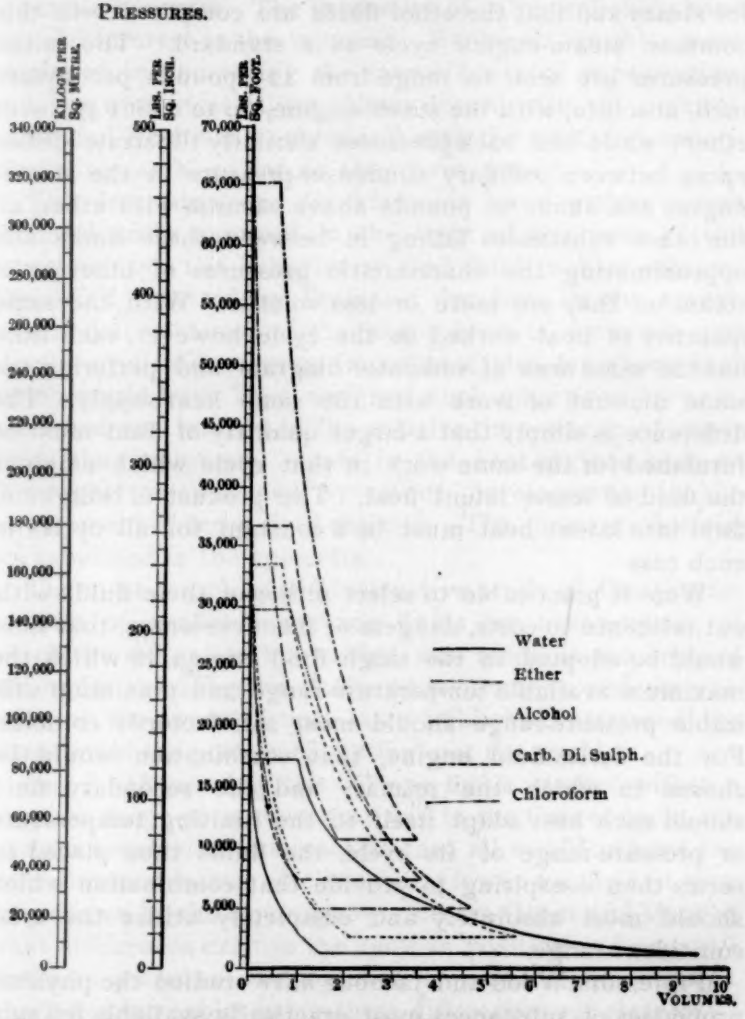

FIG. 2.—Carnot cycles. Various vapors with common temperature-range.

those of the more stable liquids and vapors are illustrated in the accompanying plate in which the Carnot cycles of water, ether, alcohol, carbon-disulphide and chloroform are

exhibited in their production within a common temperature-range.* It is here seen that the pressures usual in steam-engines and their co-ordinate pressures are assumed for steam and that the other fluids are compared with this common steam-engine cycle as a standard. The initial pressures are seen to range from 125 pounds per square inch, absolute, with the steam-engine, up to about 475 with ether; while the back-pressures similarly illustrate differences between ordinary condenser-pressure in the steam-engine and about 80 pounds above vacuum with ether, all the other substances falling in between these limits and approximating the charcteristic pressures of ether or of steam as they are more or less volatile. With the same quantity of heat worked in the cycle, however, each fluid has the same area of indicator-diagram and performs the same amount of work with the same heat-supply. The difference is simply that a larger quantity of fluid must be furnished for the same work in that cycle which employs the fluid of lesser latent heat. The product of weight of fluid into latent heat must be a constant for all cycles in such case.

Were it practicable to select either of these fluids without reference to costs, dangers or inconveniences, that fluid would be adopted, in the single-fluid engine, in which the maximum available temperature-range and maximum utilizable pressure-range should most satisfactorily coincide. For the series-fluid engine, that combination would be chosen in which the primary and the secondary fluid should each best adapt itself to the limiting temperature or pressure-range of its cycle, the fluids thus placed in series then conspiring to provide that combination which should most absolutely and completely utilize the total coincident range.

Professors Wood and Jacobus have studied the physical properties of substances most practically available for substitution as the working fluids of heat-engines in competition with steam, and their results have been published in the Transactions of the Society of Mechanical Engineers.†

* *Van Nostrand's Mag.*, 1880.

† "Transactions Am. Soc. M. E," Vol. XII, 1890.

The outcome of these determinations of important data for such substances may be seen on reference to those papers, and the tabulated results are also collated in the appendix herewith. The properties of sulphur-dioxide have especial interest at the moment. Rankine's formulas were employed in computing the latent heats of vaporization, and the numerical values closely accord with the determinations of Roche and others and with the results of experimental research, so far as they have gone.*

The determinations for ammonia have greater value than ordinarily assumed in the light of the work of the reporters upon the behavior of that fluid in heat engines. The work reported by Professor Jacobus, in the experimental determination of the latent heats of ammonia and of sulphur dioxide, assume importance also, far above that which would have been assigned such quantities by engineers had not interest in the relative importance of other fluids than water and steam in the heat-engines been so thoroughly re-awakened by recent developments in the employment of series-fluid engines. The constants derived are tabulated in the appendix.

The most complete and instructive study of the characteristics of available working fluids for heat-engines, of which the writer has knowledge, was made at the request and under the direction of the writer, in 1884, and the outcome of the investigation, later published, attracted the attention of the profession throughout the world.†

Case I.—Comparing the various fluids studied within a common range of temperature and in the Carnot cycle, the obvious conclusion was reached that all would exhibit the same thermodynamic efficiency; but it was for the first time fully shown by the investigators, Messrs. Grant and Maury,‡ what differences exist in the cycle in positive and negative works, in pressures and volumes of unit weight of fluids. The following tables bring these differences out clearly:

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* For details of methods of construction of these formulas, see "Wood's Thermodynamics."

† *Van Nostrand's Engineering Magazine*, 1884.

‡ Members A. S. M. E.

TABLE I.

Vapors.	t_1	t_2	t_4	t_5	τ_1	τ_2	τ_4	τ_5	p_1
	Fah.	Fah.	Fah.	Fah.	Fah.	Fah.	Fah.	Fah.	Lbs. on sq. foot.
Water	342	194	193	248	803·2	655·2	754·2	709·2	17,310
Alcohol	342	194	193	248	803·2	655·2	754·2	709·2	33,712
Ether	342	194	193	248	803·2	655·2	754·2	709·2	65,328
Carbon di-sulphide	342	194	193	248	803·2	655·2	754·2	709·2	36,708
Chloroform	342	194	193	248	803·2	655·2	754·2	709·2	23,845

Vapors.	p_2	p_4	p_5	λ_1	λ_2	λ_4	λ_5	D_1	D_2
	Lbs. on sq. foot.	Lbs. on sq. foot.	Lbs. on sq. foot.	Thermal units.	Thermal units.	Thermal units.	Thermal units.	Lbs. per cu. foot.	Lbs. per cu. foot.
Water	1,442	8,705	4,153	869·4	975·6	908·5	940·7	·317	·029
Alcohol	3,312	17,989	9,603	286·2	370·8	311·6	336·2	1·572	·171
Ether	10,858	36,090	21,501	99·4	144	116·3	130·1	4·911	·903
Carbon di-sulphide	7,295	22,943	14,342	108·2	140·4	121·1	130·0	2·832	·623
Chloroform	5,189	18,433	10,936	92·6	104·6	94·0	98·8	3·611	·695

Vapors.	D_4	D_5	r_2	r_4	r_5	v_1	v_2	v_4	v_5
	Lbs. per cu. foot.	Lbs. per cu. foot.				Cu. feet.	Cu. feet.	Cu. feet.	Cu. feet.
Water	·164	·081	9·37	1·83	3·51	1	9·37	1·83	3·51
Alcohol	·866	·447	8·97	1·83	3·54	·6116	5·48	1·12	2·17
Ether	2·798	1·717	6·11	1·85	3·11	·5640	3·45	1·04	1·75
Carbon di-sulphide	1·827	1·180	3·56	1·47	2·18	·8980	3·56	1·32	1·95
Chloroform	2·301	1·405	5·22	1·58	2·60	·8615	4·56	1·36	2·24

Vapors.	K	Work of Expansion.	Work of Compression.	Effective Work.	Heat used.	Efficiency.
						per cent.
Water	1	56,275	17,183	39,192	212,654	18·43
Alcohol	·966	67,857	28,645	39,192	212,654	18·43
Ether	·607	95,593	56,401	39,192	212,654	18·43
Carbon di-sulphide	·257	72,527	33,335	39,192	212,654	18·43
Chloroform	·246	71,166	31,974	39,192	212,654	18·43

The methods of treatment were those of Rankine and the physical data were derived from Regnault and Wüllner. The thermodynamic p-v diagrams are seen in the accompanying figure already referred to.

The conclusion is now perhaps evident that, while the thermodynamic efficiency is identical for all substances, as asserted by Carnot, for the ideal case and the perfect-engine cycle, it by no means follows that for less perfect cycles, or for any cycle, and with the actual engine, will the efficiencies be identical, when the influence of differences in size of engine, in pressures to be employed and limiting temperatures are studied. Final efficiency will obviously be less as the necessary volume of engine-cylinder increases.

In the above tables, the subscripts 1 and 2 indicate that the densities, D, volumes, v, etc., are measured, respectively, at the initial point of the expansion-line and its termination, at initial and final temperatures, on that line; while subscripts 4 and 5 indicate points on the compression-line employed in its location. It is seen that v_2 ranges from 3·45 to 9·37. The specific heat ranges, for the several substances, from unity with water to 0·242 with chloroform. The latent heats at the various temperatures and pressures are indicated by similar subscripts.

Case II.—A Constant Pressure-Range being adopted with the Rankine cycle, a similar comparison gives the following tables, where the symbols are taken as the accompanying statement.

BRITISH UNITS.

τ_1, absolute initial temperature on the Fahr. scale.

τ_2, absolute final temperature on same scale.

τ_4 and τ_5, absolute temperatures of intermediate points.

t_1, temperature on F. scale corresponding to absolute temperature τ_1.

t_3, temperature of condenser.

p, tension of vapor in pounds per square foot at temperature t.

λ, latent heat of evaporation in British thermal units of 1 pound of vapor at temperature t.

L, latent heat of evaporation of 1 cubic foot of vapor in foot pounds at temperature t.

v, volume corresponding to ratio of expansion r.

w, work (in foot pounds) done per cubic foot of vapor at temperature t_1.

H, total heat (in foot pounds) used per cubic foot of vapor at temperature t.

F, pounds used per horse-power per hour.

M, relative size of cylinder to produce the same power.

TABLE II.

Vapors.	r_1	r_2	r_4	r_5	t_1	t_2	D_1	D_4	D_5
Water	803	655	754	709	342	104	·317	·264	·081
Alcohol	752	617	673	637	291	104	·834	241	·119
Ether	691	537	673	637	230	104	1·400	1·132	·712
Bi-sulph. of carb. . .	727	556	673	637	266	104	1·399	·780	·487
Chloroform	747	581	673	637	286	104	2·771	·893	·531

Vapors.	p_1	p_2	p_3	p_4	p_5	λ_1	λ_4	λ_5	K
Water	17,310	1 442	153	8,703	4,512	869·4	908·5	940·7	1
Alcohol	17,310	1,442	373	4,730	2,264	313·2	358·2	383·4	·871
Ether	17,310	1,442	2,526	13,796	8,420	135·0	139·7	148·0	·569
Bi-sulph. of carb. . .	17,310	1,442	1,721	9,261	5,663	126·0	137·0	143·5	·249
Chloroform	17,310	1,442	1,020	6,763	3,911	94·7	102·6	106 4	·242

Vapors.	L_1	L_2	v_2	v_4	v_5	W	H	E	M	F
								p. c.		
Water	212,654	21,976	9·37	1·83	3·57	54,829	272,528	20·12	1	11 44
Alcohol	201,561	23,606	9·92	3·97	8·12	54,196	300,088	18·06	1·071	30·48
Ether	146,030	16,863	12·06	1·25	2·05	31,058	324,206	13·85	2·275	89·24
Bi-sulph. of carb. . .	136,219	16,038	9 00	1·87	3 06	35,545	179,973	19·75	1·480	78·15
Chloroform	158,851	17,771	10·29	2·68	4·66	47,609	232,685	20·46	1·264	90·30

The very great differences between limits and ranges of temperature and pressure, in the comparison of water and the volatile fluids, is here well brought out by observing the

data given in the two cases. The important fact that the practical limits of temperature and of pressure in heat-engines employing these various fluids as working substances are necessarily widely separated in each fluid, and are in no case coincident, is also evident; while the possibility of securing a higher net efficiency from a system in which the one fluid is used in supplement of another in such manner as to more nearly bring the upper limit of manageable temperature to coincide with the limit of allowable pressure and the lower limit similarly depressed to a point at which the pressure and the temperature range have coincident practical boundaries, becomes no less obvious.

In this case, we find sensible differences in efficiency, naturally, and, in the case of water and ether, a wide difference, in the relation of 20 per cent. to 14. The relative sizes of engine to produce equal power, M, varies between the standard, unity, for water and steam, to 2·27 for ether and 1·48 for carbon-disulphide. This means that, at low pressures certainly, the larger engine required may place the more volatile substance at a real disadvantage beside steam. The values of F, the weights of the fluid demanded in the unit of time for the unit of power, vary more strikingly than any other figures given, ranging from 11·44 pounds per horse-power hour for steam to about 90 pounds for ether and chloroform. This is not, however, as important a matter as it might seem at first; since it only means that a larger quantity of fluid is required to convey a given amount of heat where the "latent heat" is a small, than where, as with water, it is a large quantity. The figures, however, bring out very strikingly the fact that, in such comparisons, it is only the measures of efficiency and of thermal units per unit of power and of time that give the measures of the cost of power. The phrase, "pounds of steam per horse-power hour," has here no significance.

Another interesting point appears in this comparison: that the common pressure-range adopted, as fixed by customary working of the steam-engine, is not suitable for all fluids. With both ether and carbon-disulphide, the terminal pressure falls below the back-pressure line, and their work-

ing range, for best effect, should be lifted to a higher point on the scale.

Case III, resembling Case II, except that the terminal pressure is elevated sufficiently to evade the objection just mentioned, the following results are obtained:

TABLE III.

Vapors.	r_1	r_2	r_4	r_5	l_1	l_5	D_1	D_2	D_4	D_5
Water	803	655	754	709	342	104	·317	·029	·164	·081
Alcohol	752	619	673	637	291	104	·834	·080	·241	·119
Ether	691	583	673	637	230	104	1·400	·310	1·132	·712
Carbon di-sulphide	727	601	673	637	266	104	1·399	·289	·780	·487
Chloroform	747	601	673	637	286	104	2·171	·293	·893	·531

Vapors.	p_1	p_2	p_3	p_4	p_5	λ_1	λ_4	λ_5	K	L_1	L_2
Water	17,310	1,442	153	8,703	4,512	869·4	908·5	940·7	1	212,650	21,980
Alcohol	17,310	1,507	373	4,730	2,264	313·2	358·2	383·4	·871	201,861	24·565
Ether	17,310	3,524	2,526	13,796	8,420	135·0	139·7	148·0	·569	146,030	47,936
Carbon di sulphide	17,310	3,245	1,721	9,261	5,663	126·0	137·0	143·5	·249	136,219	33·331
Chloroform	17,310	2,092	1,020	6,763	3,911	94·7	102·6	106·4	·242	158,851	24,885

Vapors.	r_2	r_4	r_5	W	H	E	M
						per cent.	
Water	9·37	1·83	3·51	54,829	1,330,639	20·12	1
Alcohol	9·51	3·97	8·12	53,786	1,465,207	17 92	1·035
Ether	4·85	1·25	2·65	33,357	1,094,722	14 88	·845
Carbon di-oxide	4·31	1·87	3·06	33 358	878,729	18·53	·756
Chloroform	7·24	2·68	4·66	44,894	1,136,084	19·29	·944

These figures show an evident improvement in the working conditions affecting the more volatile fluids, and in this case steam has highest efficiency and carbon-disulphide requires the smallest engine for the same work.

[*To be continued.*]

Book Notices.

The Chemistry of the Terpenes. By F. Heusler, Ph.D. Authorized translation by Francis J. Pond, M.A., Ph.D. 8vo, 435 pages and index. Philadelphia: P. Blakiston's Son & Co. Cloth. $4 net.

This excellent volume is an acceptable contribution to chemical literature. Great progress has been made in late years in the study of the terpenes, the principal ingredients of the essential or volatile oils. Much of the original literature is in other languages than English; moreover, owing to the rather restricted applications of the researches, the ordinary text books have given but brief summaries. A generation ago, indeed, all that was known about the essential oils might have been expressed in a very few pages. The text-books of that day usually gave a brief account of some of the more important oils, stating the striking isomerism observed with regard to the hydrocarbons present. The investigations of O. Wallach have been the principal "road-breaking" element in the modern progress. He succeeded in solving the general chemistry of the essential oils so that the examination of them can be systematized and the different proximate constitutents identified with comparative ease. It is now known, that while the natural volatile oils consist largely of hydrocarbons, yet these are usually accompanied by oxidized bodies, analogous to the camphors. The group of camphors has, therefore, been brought into close structural relations to the terpenes and is considered in this book. Any one who has given even superficial attention to the trade literature in this field is aware of the great progress that has been made in the production of synthetics. Not only have many of the natural products been accurately imitated, but derivatives and isomers have been obtained in great number.

The translation of Heusler's book will afford an opportunity to English-speaking students to get a synopsis of the present state of the subject. The translation is very well done. We commend the care taken to avoid mere literal rendering of German idioms and German nomenclature. The mechanical execution of the book is also good and, altogether, it reflects credit on author, translator, printer and publisher. It relates principally to the pure chemistry of the topic; the analytic and industrial features are not within its scope. H. L.

Histoire des Mathématiques dans l'Antiquité et au Moyen Age. Par H. G. Zeuthen, Professeur à l'Université de Copenhague. Edition Française, Revué et Corrigée par l'Auteur. Traduite par Jean Mascart. Un volume in-8 de xv-296 pages, avec 31 figures. Paris: Gauthier-Villars, 1902. (Price, 9 fr.)

The introduction of this work treats of prehistoric mathamatics, and of the state of the science among the Egyptians and Babylonians. Following are chapters on mathematics as developed by the Greeks, and in India. The work concludes with an historical sketch of the sciences during the Middle Ages, especially dealing with the contributions of the Arabian mathematicians and the development of the sciences in Europe. W.

Die Eis-und Kälteerzeugungs Maschinen; ihr Bau und ihre Verwendung in der Praxis. Ein Compendium der gesammten Kälte-Industrie. Von Richard Stetefeld, diplomierter Ingenieur zu Pankow, Berlin. Stuttgart: Verlag von Max Waag, 1901.

This treatise makes a large octavo volume of nearly 500 pages, with thirteen plates and 340 illustrations in the text.

The subject is divided into, (1) an historical and descriptive portion, in which is given a review of the development of the art of refrigeration, and a series of chapters giving detailed descriptions of the various types of refrigerating machines, cold-air machines, absorption machines, vacuum machines; (2) a theoretical part, in which is presented the fundamental physical principles and the mechanical theory of heat; (3) a constructive part, treating in detail of the several mechanical elements—compressors, condensers, etc.—entering into the construction of refrigerating machines; (4) erection and operation; (5) installation, treating of the special location of machines for different kinds of service—in breweries, abattoirs, cold-storage houses and special forms of service; (6) duty-tests of refrigerating machines in practice, in which are treated instruments and methods, with examples. A series of tables useful for reference is appended.

The treatise is the work of an engineer who had an extensive practical experience, and should prove a useful addition to the literature of the subject.

W.

Armature Windings of Direct-Current Dynamos: Extension and application of a general winding rule. By E. Arnold, Engineer and Assistant Professor in Electrotechnics and Machine Design at the Riga Polytechnic School. Translated from the original German by Francis B. De Gress, M.E., Chief of Testing Department, Crocker-Wheeler Company. With 146 illustrations. 8vo, pp. vi + 124. New York: D. Van Nostrand Company. 1902. (Price, $2.)

In this work Professor Arnold has formulated a rule for the solution of the problems in winding armatures for direct-current machines, which not only embraces all known windings—ring, drum and disk types—but also affords a general solution of the winding problem.

The designs and illustrations treated include all of the well-known forms and a number of new designs. The work will doubtless be very useful to electrical engineers.

W.

Electric Power Transmission: A practical treatise for practical men. By Louis Bell, Ph.D. Third edition, revised and enlarged; pp. 952. New York: *Electrical World and Engineer,* N.D.

The author has thoroughly revised the present edition of this well-known treatise, bringing it in touch with the present, and with the result of considerably enlarging it by the addition of new matter and numerous illustrations of recent plants and apparatus. A chapter on Commercial Electrical Measurements has been added; and in the final chapter on High Voltage Transmission, the author has sought to incorporate the latest developments of the art.

The present edition is illustrated with 21 full-page plates and 285 cuts in the text.

W.

Tir des Fusils de Chasse. Par Journée, Lieut-Colonel du 69e Régiment d'Infanterie. 2e edition, entirement refondue. Paris: Gauthier-Villars, 1902.

The work is a complete treatise on sporting-arms and ammunition.

The first edition of this work, issued about twelve years ago, contained the results of a considerable number of experiments made with the old type of sporting gunpowders then in use.

In the present edition the author has supplemented these results by a series of similar experiments made with the modern pyroxyline powders which have come largely into use for sporting-arms. W.

Text-Book of Qualitative Chemistry for studies of water solution and mass-action. By Albert B. Prescott, Ph.D. and Eugene C. Sullivan, Ph.D. Eleventh edition, entirely rewritten. New York: D. Van Nostrand Company, 1902. (Price, $1.50.)

The eleventh edition of this work has been thoroughly modernized, and it can be commended to teachers and students of the science. W.

A Philosophical Essay on Probabilities. By Pierre Simon, Marquis de Laplace. Translated from the sixth French edition by Fred Wilson Truscott, Ph.D., Havre, and Fred'k Lincoln Emory, M.E., Nor. Poly. Inst. First edition. First thousand. New York: John Wiley & Sons. London: Chapman & Hall, Limited, 1902. (Price, $2.)

The translators appear to have made an elegant and admirable English version of the classic work of Laplace. W.

Franklin Institute.

[*Proceedings of the Stated Meeting held Wednesday, September 17, 1902.*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, September 17, 1902.

President JOHN BIRKINBINE in the chair.

Additions to membership since last report, 17.

The Secretary reported the resignations of Prof. Arthur Beardsley and Henry C. Brolasky from the Board of Managers.

An election resulted in the choice of Mr. Henry T. Townsend in place of Professor Beardsley, and of Mr. Jawood Lukens in place of Mr. Brolasky.

Under suspension of the rules, amendments to the By-Laws, offered respectively by Profs. F. L. Garrison and L. F. Rondinella, were adopted, severally and collectively, as follows:

ARTICLE III.—*Members.*

SEC. 7. Any member whose dues are more than three months in arrears shall be notified by the Actuary. Should such dues not be paid when they

become six months in arrears, the privileges of membership shall be suspended. When nine months in arrears such member shall be again notified, in form to be prescribed by the Board of Managers, and if such dues become one year in arrears, the said member shall forfeit all connection with the Institute. The Board of Managers may, however, for cause by it deemed sufficient, extend the time for payment and for the application of these penalties.

The Board of Managers may, for sufficient cause, temporarily excuse from payment of annual dues any member who, from ill-health, advanced age, or other good reason assigned, is unable to pay such dues; and the Board may remit the whole or part of dues in arrears, or accept in lieu thereof desirable additions to the library or collections.

Every person admitted to membership in the Institute shall be considered as liable for the payment of dues until he shall have resigned, been dropped or have been relieved therefrom by the Board of Managers.

ARTICLE VI.—*Election of Officers, Etc.*

SECTION 1. An election for officers and for members of the Committee on Science and the Arts shall be held on the date of each Annual Meeting. At this election the President, the Secretary and the Treasurer shall be elected to serve one year, and one Vice-President, eight Managers, one Auditor, and twenty (20) members of the Committee on Science and the Arts to serve for three years, or until their successors are elected.

SEC. 2. Voting at annual elections shall be by letter ballot, and no vote shall be cast by proxy, nor received from a member in arrears.

SEC. 3. Nominations for the annual election for officers and for members of the Committee on Science and the Arts shall be presented in writing at the stated meeting in the month of December. Each nomination paper must be signed by at least two members in good standing who shall certify that the candidate will serve if elected. After the nominations are closed, the President shall appoint seven members, who are neither officers nor nominees, to act as tellers of the election. The list of nominees shall promptly be posted at the Institute and incorporated (with directions for voting) in a ballot to be sent to each member by the Secretary at least one week before the date of the election. Each ballot shall be acompanied by a return envelope addressed "To the Tellers of Election" and provided with a space for the signature of the member voting.

SEC. 4. On the date of the annual election, and at an hour previously designated by their chairman, the tellers shall meet at the Institute and count all legal votes that have been received by mail or placed in the ballot box before 8 o'clock P.M.; and when the count is completed they shall report to the annual meeting of the Institute the total number of ballots cast, together with the number of votes received by each candidate. Thereupon, the presiding officer shall announce the names of the candidates who received the plurality of votes for each office, and shall declare them elected officers of the Institute for the ensuing terms.

ARTICLE XII.—*Of Commitees.*

(Committee on Science and the Arts.)

SEC. 2 (paragraph 7). The committee shall report all vacancies occurring in their body, whether by neglect of duty or otherwise, to the stated meeting of the Institute next ensuing, at which such vacancies shall be filled by election.

ARTICLE XIV.—*Order of Business.*

SEC. 3. At the Annual Meeting, the tellers' report may be received and read by the Secretary immediately after the conclusion of any number of the order of business.

ARTICLE XV.—*Rules.*

Omit Rule Seven.

Rule Eight becomes Rule Seven.

ARTICLE XVI —*Board of Managers.*

SEC. 5. All vacancies in the Board of Managers shall be filled by an election at the next stated meeting of the Institute.

ARTICLE XVII.—*Amendments.*

Proposals for amendments to these by-laws shall be posted at the Institute at least ten (10) days before a stated meeting, and may then be presented in writing signed by at least two members in good standing. By a majority vote of the members present at this meeting they may be considered, amended, referred, postponed, rejected, or ordered to be voted upon at the date of the next stated meeting. In the latter event, the President shall appoint tellers, and the vote shall be taken by letter ballot and reported at the next stated meeting in the manner provided in Article VI for the election of officers. If two-thirds of the votes cast are in favor of the proposed amendment, it shall be declared adopted; except that amendments to Article II, relating to Capital Stock, must be ratified by a majority of the stock represented at a subsequent meeting specially called for this purpose.

Mr. S. L. Sinclair, representing the D'Olier Engineering Company, of Philadelphia, read a paper on the De Laval Steam Turbine, which was illustrated by an exhibition of parts of the apparatus and numerous lantern slides.

After some discussion, the subject was referred to the Committee on Science and the Arts.

Mr. F. E. Ives exhibited and described an improved apparatus for making stereoscopic photomicrographs. The subject was illustrated by an exhibition of the apparatus and of a number of stereoscopic views made with the apparatus. The invention was referred to the Committee on Science and the Arts.

The President announced that the question of the "Mitigation of the Prevailing Smoke Nuisance within the City Limits" had been reserved for discussion, and, at the request of the presiding officer, the Secretary read a brief abstract of the action taken by the Institute on this subject in the year 1897, at the request of the local Bureau of Health. The sentiments of the Institute were finally expressed in the following preamble and resolutions, which were

formally transmitted to the Bureau of Health and to the Presidents of Councils, viz :

WHEREAS, The Bureau of Health of the city of Philadelphia has requested the Franklin Institute to discuss the question of Smoke Prevention, and to offer practical suggestions relative thereto; and,

WHEREAS, The use of bituminous coal for fuel is increasing in this city and is likely so to continue in the future; and,

WHEREAS, It appears, from the testimony presented to the Institute, that it is practicable to burn bituminous coal in suitably constructed furnaces without creating a smoke nuisance;

Therefore, Be it resolved, that it is the opinion of the Institute that the continuous or frequent discharge of dense black smoke from furnaces of stationary boilers is avoidable, and should not be permitted within the city limits.

Resolved, That the emission of smoke from locomotives and furnaces, other than those of stationary boilers, might be greatly reduced if the co-operation of firemen and employers were enlisted with an earnest intention to abate the nuisance; and more especially, could the railway companies be induced to use anthracite coal or coke in the furnaces of the locomotives used for local service in the train-yards within the city limits.

Resolved, That a copy of these resolutions be sent to the Mayor, to the President of the Bureau of Health and to the Presidents of City Councils.

Mr. John M. Hartman, member of the Institute and of City Councils, was thereupon invited to open the discussion. The subject was discussed by Messrs. Hartman, Wm. E. Lockwood, Wm. B. LeVan, Spencer Fullerton, Wm. Trautwine, the Chairman and others.

Adjourned.

WM. H. WAHL,
Secretary.

Committee on Science and the Arts.

(*Abstract of proceedings of the stated meeting held Wednesday, Sept. 3, 1902.*)

MR. THOMAS P. CONARD in the chair.

The following subjects passed first reading :

(No. 2227.) *Electromagnetic Geological Balance.*—F. J. Estrada, Mexico.

(No. 2231.) *Screw-Cutting Lathe.*—Otto E. Evans, York, Neb

(No. 2232.) *Improvements on the Manufacture of Open-Hearth Steel.* – Benjamin Talbot, Philadelphia.

(No. 2236.) *Crushing and Grinding Rolls.*—Gerdt A. Gerdtzen, Winona, Minn.

(No. 2241.) *Compartment-Drawer Bottom* —John Gowdy, Philadelphia.

(No. 2244.) *Blount Door-Check* —The Yale & Towne Manufacturing Company, Stamford, Conn.

(No. 2245.) *System of Motor Control.*—H. Ward Leonard, Bronxville, N. Y.

In the absence of a quorum, final action on a number of reports was postponed. Adjourned.

W.